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UNITED STATES AIR FORCE
INSTALLATION RESTORATION PROGRAM (IRP):
STRATEGIES FOR INVESTIGATING
MIGRATING CONTAMINATED GROUNDWATER

THESIS

Michael L. DeWall
Captain, USAF

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UNITED STATES AIR FORCE
INSTALLATION RESTORATION PROGRAM (IRP):
STRATEGIES FOR INVESTIGATING
MIGRATING CONTAMINATED GROUNDWATER

THESIS

Presented to the Faculty of the School of Systems
and Logistics of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Masters of Science in Engineering Management

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Approved for public release; distribution unlimited

Preface

Groundwater contamination has become a major issue of consideration throughout the country. Department of Defense officials have taken steps to ensure water at DoD installations is monitored for contamination using the Installation Restoration Program (IRP). The IRP provides for groundwater investigation, monitoring and cleanup to return water to an acceptable quality.

This report will aid the Environmental Manager at Air Force installations in identifying various investigative strategies employed within the Air Force and the private sector. A thorough understanding of groundwater and subsurface soil characteristics are essential to obtain maximum improvement of groundwater quality while remaining within a restricted budget. The report clearly demonstrates that preliminary investigations focusing on soil and groundwater characterization can greatly reduce the effort and expense of groundwater investigation and restoration.

I would like to thank my advisor, Major Mark Goltz and my reader, Major Hal Rumsey, for their expert help and advice throughout the year and especially during the final compilation of this report. I would also like to thank my wife, Debbie, for her understanding. She handled the bulk of the home front responsibilities, caring for our three year-old daughter, Danielle, and our newborn son, John-Michael.

Michael L. DeWall

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Abstract

The intent of this thesis was to review the strategies being used by the environmental community within the Air Force and private sector to investigate, confirm, and quantify soil and groundwater contamination at government installations. Within the DoD these investigations take place under the Installation Restoration Program (IRP). The IRP is the DoD equivalent to the EPA Superfund program.

The study found strategies currently used within DoD for IRP Superfund remedial investigations are too long and drawn out. The goal of Remedial Investigation (RI) is to confirm and quantify soil and groundwater contamination. Often, RI costs exceed estimates, time schedules are surpassed and environmental regulators and local residents become distressed over the apparent lack of progress being made.

The strategy being employed at most Air Force installations centers around contamination Plume Delineation (PD) during the RI. PD often does not reveal adequate information regarding movement and spread of contaminants.

An alternative strategy is Transport Quantification (TQ) which is a process of identifying and quantifying groundwater flow characteristics prior to, or during, contaminant investigation. Emphasis is placed on surficial and geological investigations and groundwater flow models.

The Air Force Logistics Command has adopted forms of the TQ strategy for all seven of its bases in an attempt to better understand their contamination problems.

Environmental managers at F.E. Warren AFB, WY (SAC) have estimated a savings of approximately $100 thousand in investigation costs after implementing investigations similar to TQ on the southeast portion of the base.

Second, a severe lack of manning within the environmental community, with respect to technical program managers at many installations and some higher headquarters levels, exists. Without technical personnel to administer the IRP at all levels, the program will continue to be run ineffectively.

To further increase problems, the study revealed a lack of adequate data transfer and communication between base level offices and higher headquarters, between HQs, and also between the services. To help bridge these gaps, the AF Engineering and Services Center is developing an environmental decision support system and USAF OEHL is compiling an IRP data base.

It is necessary to increase emphasis on the IRP at all levels of management. Positions must be funded for technical staff with salaries commensurate with the civilian sector. New investigative strategies must be considered with open mindedness, not centered entirely on cost, but also on the effectiveness of the process.

UNITED STATES AIR FORCE
INSTALLATION RESTORATION PROGRAM (IRP):
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I. Introduction

General Issue

Many Air Force installations are contaminated from the past practice of depositing hazardous waste in landfill sites and/or from various types of surface and subsurface spills and leaks. These contaminants are transported beneath the surface via groundwater movements. The Air Force must identify and select a means for delineating the extent of the spread of these contaminants so that remedial action may be carried out to recover the environment and protect the health and well-being of the community, all while working within a limited budget. Failure to completely identify the contaminated region and understand the hydrogeological setting may lead to numerous change orders, inflated costs, or incomplete cleanup during the remedial action.

Specific Issue

The focus of this research is to identify strategies currently used within the Air Force or private sector that are most effective in delineating the spread of contamination in subsurface groundwater. It will also identify some strategies that are not so successful, thereby allowing the Environmental Manager to compare and contrast effective and less than effective processes.

Background

For many years concern has increased within government and the community-at-large over the issue of environmental pollution and its direct and indirect effects on human health and well-being.

Dr. Jay H. Lehr of the National Water Well Association wrote, "America has finally reached its tolerance level for the indiscriminate, ignorant and wrong-headed manner by which we have disposed of industrial waste and applied, stored and transported chemicals these past 40 years" (28:2).

Environmental Law. Both federal and local governments have increased efforts to deter the occurrence of additional hazardous waste contamination sites and to propagate clean up of those sites that already exi... This action comes in the form of several laws that provide the authority to federal, regional, and local officials to enact procedures for the location, quantification, cleanup, and monitoring of contaminated sites and groundwater.

CERCLA. The United States government has established the Environmental Protection Agency (EPA) to monitor and protect the environment. It has also enacted laws such as the Resource Conservation and Recovery Act of 1976 (RCRA) that the EPA may draw upon in exercising its authority. The Federal Government enacted the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), more commonly known as the Superfund, to provide funding for the study and cleanup of contaminated sites.

National Contingency Plan. The National Contingency Plan (NCP) is the part of CERCLA that contains directions for implementing the process of remediation at a hazardous waste site. Sites placed on the National Priorities List (NPL) are investigated and remediated using the NCP process. The NPL is a list of the hazardous sites that have been ranked as having the greatest potential for causing environmental problems that could affect humans, plants or wildlife.

"There are several steps in the NCP. The first step involves Discovery and Notification (D&N). When a hazardous waste site is found, appropriate federal, state, and local officials must be notified" (37).

The second step is the Preliminary Assessment (PA). Here, readily available information regarding the extent, nature, source and magnitude of the potential hazardous site is gathered and studied to ascertain if, in fact, there could be a problem at the site. If it is determined that there is an immediate threat at the site, removal action may be warranted. "Removal Action (RA) is simply an emergency action taken to reduce the threat of exposure to contaminants at a site" (37).

Likewise, if it is determined that there is not a problem at the site and no action is required, the study at that site may be terminated.

The third NCP step undertaken, in the event the PA reveals that a hazard could or does exist, is a Site Inspection (SI). The SI involves the analysis of samples taken from the site to determine types, amounts, and general location of hazardous wastes and their potential for migration (37).

The fourth NCP step is to rank the site based on the information gathered in the PA and SI steps. A Hazard Ranking System (HRS) is used and those sites that attain a score of greater than 28.5 are placed on the NPL.

The next step is to initiate a Remedial Investigation. This portion of the NCP builds the data base for the hazardous site that will help plan the remedial action. The information obtained during the RI includes identifying and characterizing the source or sources of the contamination, identifying transport pathways of migration of the contaminants, and identifying the receptors of the contaminants, both human and environmental (37).

As stated, the RI provides information for conducting the Feasibility Study (FS). The FS basically assesses the data acquired during earlier steps in the NCP and considers different alternatives for remediation of the hazard, both immediate and long-term. There are many factors to consider while performing the FS. The effectiveness and efficiency, as well as benefit versus cost, of each alternative must be weighed (37).

The FS must also address the problem of what to do with the hazardous substances once they have been removed from the site. Are they volatilized into the atmosphere and, if so, will the effects to the air we breath be even more disastrous than those to the water and ground? Where do you dispose of solid or liquid hazardous wastes? The FS must address each of these problems before actual remediation of the site can begin.

The RI/FS is perhaps the most critical step in the IRP process. It is during the FS that the actual contaminated region is considered for remedial activities and a cleanup design and methodology are chosen. If a less than accurate or incomplete delineation of the contamination is identified, the resulting RA will not accomplish the intended result. Likewise, if an inappropriate approach toward test well placement and analysis for contamination identification is selected for implementation during the RI, (the confirmation and quantification phase), it can only be expected that the RA will fail. Because of the great importance of this transition, research for this thesis centered around the Remedial Investigation segment of the NCP process, reviewing strategies presently employed.

After the RI and FS have been completed, the next step is to prepare a Record of Decision (ROD). The ROD is the final step before actual remediation takes place. It signifies that all steps in the NCP have been followed and the requirements of CERCLA have been met. State and local authorities are given the opportunity to review the ROD and make comments concerning the decisions made (37).

The next step, once the ROD has been approved and accepted, is to perform the Remedial Action (RA) or the physical actions which will remediate the hazardous waste site or threat of release (37).

The final step in the NCP is to establish Post Closure Monitoring (PCM). PCM may be required to continue for many years; in some cases, long beyond the period of time alloted for funding under the DoD equivalent to the Superfund, the Defense Environmental Restoration Account (DERA) (37).

SARA. In 1986 Congress passed the Superfund Amendments and Reauthorization Act (SARA). Under SARA, DoD services were brought under the authority of CERCLA. For Defense sites placed on the NPL the DoD is now required to follow NCP procedures. Now that the DoD has been taken under the umbrella of CERCLA, the DoD environmental restoration programs must follow the NCP guidelines and regulations (37).

IRP. A separate program was enacted for the DoD to aid the services in complying with certain environmental requirements. This program is called the Installation Restoration Program (IRP). The IRP is an environmental investigative and funding program that is in use throughout the services and is administered at virtually all levels and commands. Instituted in 1975, the IRP actually preceded CERCLA as CERCLA was not adopted until 1980. Once passed, CERCLA became the measuring stick for all environmental cleanup efforts nationwide.

DERP. The IRP has a codified statutory basis, derived from SARA in 1986, which supplies its authority, called The Defense Environmental Restoration Program (DERP). Much time, effort, and money have been expended evaluating the environment and those operations or processes that might contribute to environmental pollution (37).

The Air Force is remediating hazardous waste sites using the Air Force IRP. The Air Force has taken an energetic approach to identifying possibly contaminated sites at installations and taking action to monitor and cleanup sites determined to be hazardous.

The Air Force Installation Restoration Program Management Guidance booklet states:

> The U.S. Air Force, due to its primary mission of defense of the United States, has long been engaged in a wide variety of operations dealing with toxic and hazardous materials. This problem has been recognized by the Department of Defense (DoD), and action has been taken to identify the locations and contents of past disposal sites and to eliminate the hazards to public health in an environmentally responsible

manner. The DoD program is called the Installation Restoration Program (IRP) [13:1].

The original IRP was comprised of four (4) phases. Phase I was the records search which was usually an installation-wide study. "The assessment considers whether or not each site may pose hazards to the public health or environment" (13:2).

Phase II was the confirmation/quantification phase of the IRP. "The objectives of Phase II are to confirm the presence or absence of contamination; to determine the extent and degree of contamination; and to decide whether no action, emergency response, remedial action, or long term monitoring is appropriate" (13:2).

Phase III was a technical base development that included, ". . . implementation of research requirements and technology for objective assessment of environmental effects" (13:3).

Phase IV was the final phase and was conducted in two steps: Phases IV-A and IV-B. Phase IV-A included the preparation of the statement of work for the Remedial Action Plan (RAP) and the preparation of the RAP itself. These two documents formed the guidelines under which the hazardous site would be cleaned up. They indicated the degree to which the site was contaminated and to what extent it must be reclaimed. "The RAP is a five-step process by which remedial actions are selected and described" (13:29).

Previous to SARA, CERCLA procedures served only as guidelines for the services. Each service was free to pursue varied avenues in complying with DoD IRP requirements and they did. The Air Force stuck closest to the original four phase IRP approach but decentralized its authority for control of the program down to the MAJCOM level and ultimately down to installation level for implementation (37).

Upon passage of SARA, it has become increasingly difficult to continue using the four-phased approach and terminology. In fact, the Air Force is now adopting the CERCLA EPA terminology of the NCP with Preliminary Assessment (PA) taking the place of Phase I, Remedial Investigation and Feasibility Study (RI/FS) in lieu of Phase II and Phase IVA, and Remedial Action replacing Phase IVB. Figures 1 and 2 show the relationship of the IRP four-phased approach and the EPA NCP terminology. This change in the basic terminology and structure of the IRP eliminates ambiguities and differences in strategies that have confused managers and decision-makers for DoD and EPA in the past.

According to Mr. Scott Mallette of the Wright-Patterson AFB Environmental Management Office, many installations are downgrading Phase II quantification data gathered under the old IRP format to background and historical data to support further quantification under

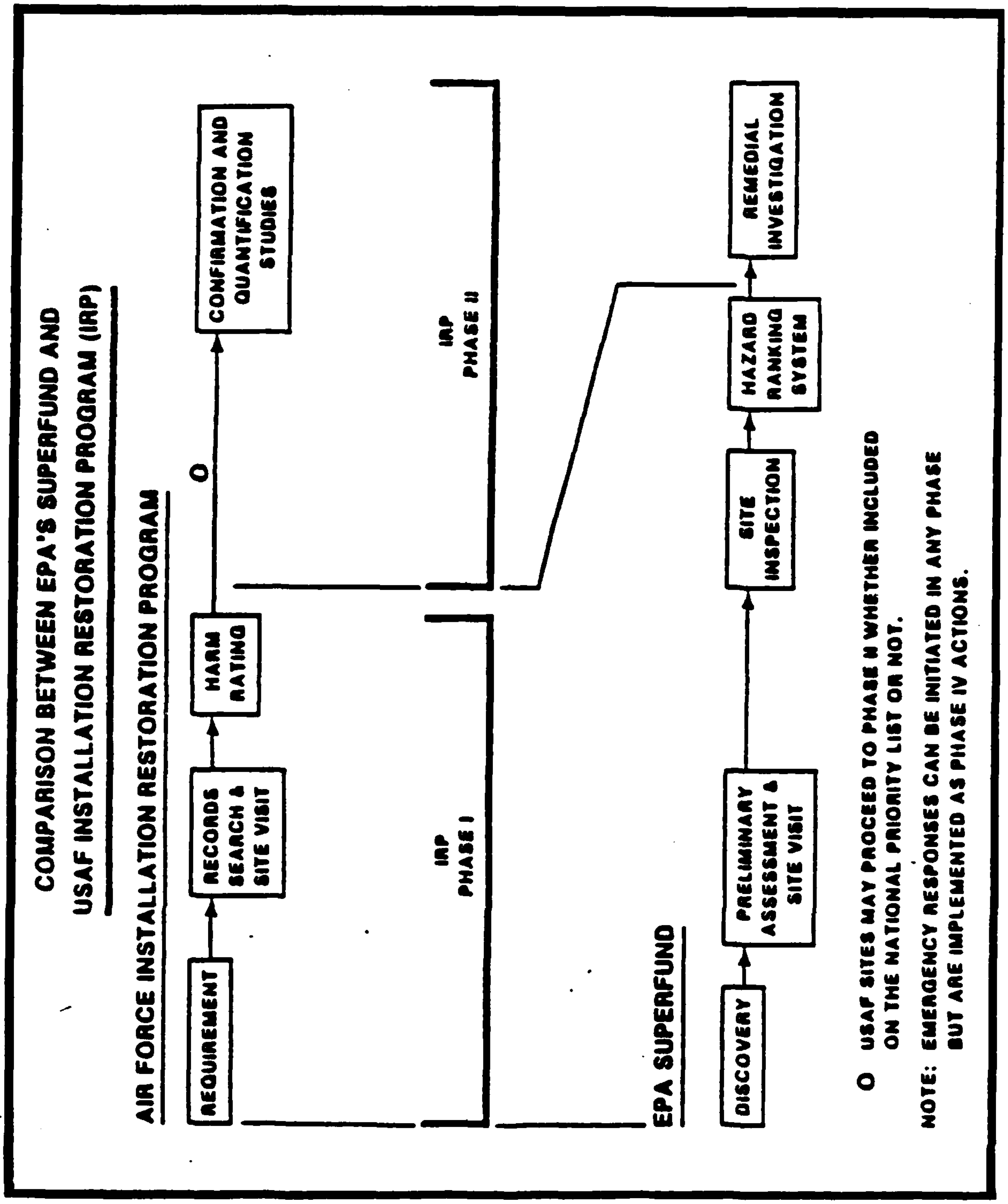

Figure 1. Comparison Between EPA's Superfund and USAF IRP Phases I & II (14)

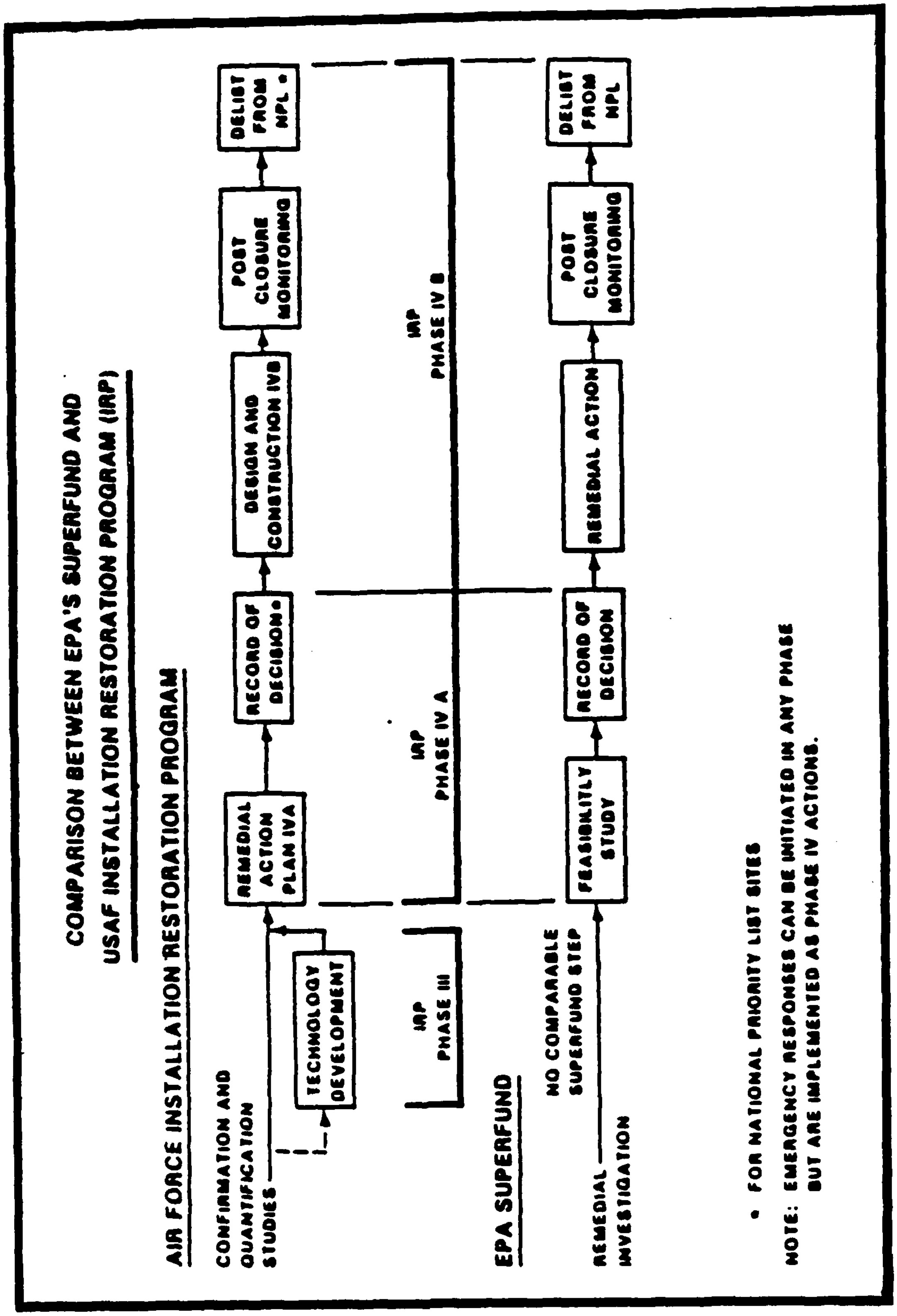

Figure 2. Comparison Between EPA's Superfund and USAF IRP Phases III, IVA, and IVB (14)

Remedial Investigations (RI) of the EPA format (27). Consequently, much of the work accomplished under the original Phase concept must be reevaluated to surmise its value under the EPA concept. The reason for this action is due to incompleteness and incompatibility of data acquired under the old Phase II approach as it is compared to the EPA and CERCLA standards.

The IRP Budget. CERCLA or Superfund monies are expressly denied use by DoD facilities. A separate DoD account was created to distribute funds to conduct IRP activities and is known as the Defense Environmental Restoration Account (DERA). Under SARA, a central DoD transfer account was established from which DERA funds are transferred to service accounts (15).

The IRP is an expensive venture. Table 1 contains cost data extracted from the syllabus for a recent Air Force IRP Workshop. Projected DERA expenditures for the AF IRP through 1997 were included.

IRP 1987 estimated costs represent a nearly $4.13 billion commitment to identifying and cleaning up contamination at AF installations (14). Looking at the expected costs for a particular installation, Mr. Mallette commented many Wright-Patterson AFB individual site costs could exceed $500,000 (29). With 39 sites under investigation at Wright-Patterson, the total cost for that base alone could exceed $19.5 million. When this great an

Table 1

Projected IRP Expenditures Through 1997 ($ Million) (14)

FUNDING OBJECTIVE	TOTAL PROJECTED REQUIREMENTS	SPENT THROUGH FY 1987	REMAINING REQUIREMENTS
PA/SI (Phase I)	10.0	7.0	3.0
RI/FS (Phase II)	220.0	160.0	60.0
TD (Phase III)	110.0	35.0	75.0
RD/RA (Phase IV)	3,000.0	190.0	2,810.0
Third Party	500.0	14.0	486.0
Other	290.0	32.0	258.0
IRP TOTAL	4,130.0	438.0	3,692.0

expense is anticipated, it would only be appropriate to perform the evaluation and cleanup in the most cost effective and efficient manner possible.

It is obvious that the final cost of the IRP is dependent on many factors. Each installation is required to conduct a separate IRP which is funded from the single DERA source. The most effective and efficient means for remediating contaminated sites are primary goals of the IRP. Attainment of these goals begins with proper identification and quantification. A better understanding of the strategies available to conduct these efforts will go a long way toward achieving these goals.

Contaminant Transport. The first step in determining how to correct or clean up pollution is to find the origin of the problem and determine the extent of its spread. In the article, "Delineation of Landfill Migration Boundaries Using Chemical Surrogates," the authors stated:

> The introduction of chemicals into the environment may occur as a result of spills, process effluents, or releases from landfills. The need to monitor and control these releases, especially at landfill sites no longer in operation, has prompted the investigation of ways of monitoring chemical migration. Particular emphasis is now being placed on chemical migration in ground and surface water (44:145).

In the past, groundwater flow characteristics were considered to be somewhat of a mystery. Dr. Lehr writes:

> Before scientific techniques of ground water hydrology were developed, the natural laws that control water movement were unknown. This led to the concept, preserved in case law, that the occurrence and movement of water in the ground is mysterious and occult and that the principles of its behavior cannot be known (27:1).

This presented a problem considering groundwater sources are often interconnected over vast stretches of a region. Dr. Lehr says, "It is not uncommon for aquifers (water bearing rocks) to be connected for hundreds or even thousands of square miles" (27:1).

Therefore, a more complete knowledge of groundwater movement within a given aquifer or series of connected aquifers will assist immensely in identifying the extent and concentration of pollutants far removed from the original point of pollution.

Fortunately, the speed and direction of groundwater movement through various types of rock formations and soils can be determined. Using today's knowledge of groundwater hydrology, it has been proven that though these aquifers may be interconnected over such broad areas, the time involved to contaminate such an area would be considerable. Dr. Lehr writes, "Ground water moves slowly through the earth, in most cases only a few feet per year" (27:1).

Conversely, this flow phenomenon can work against cleanup efforts. Dr. Lehr points out, "Ground water velocity is particularly important in water pollution problems. Due to the slow rate of movement, an area once contaminated may be unusable for years" (27:1).

For the reasons mentioned above, it is important to evaluate and understand the groundwater flow characteristics at and around a suspected or confirmed hazardous site. Appropriate geological and hydrogeological surveys and studies are required. These studies involve determining the flow characteristics of groundwater and a complete evaluation of the geological rock and soil characteristics of the affected area. Water flow rates within aquifers are determined by analyzing the permeability coefficients of the soil and rock formations contaminated water must flow through. Flow direction, estimated velocity and volumes are determined by identifying the various changes of the soil and rock formations in depth and thickness, and in size, area, and direction of a particular formation with respect to other formations. Knowing the subsurface soil and rock formation characteristics plays a major role in determining groundwater flow characteristics (23:27-31).

Case Study. There are many well-known examples of hazardous waste sites whose impacts on man and the environment are well documented. One of the most famous is the site located in a suburb of Niagara Falls, New York, known as Love Canal. It was determined that the chemical landfill located there contained hazardous waste that was endangering the lives of the area's citizens. The town was evacuated and environmental studies continued.

In his article, "Modeling Ground-Water Flow at Love Canal, New York," James Mercer determined from the geological data that the Love Canal site was composed of several different layers of soil and rock formations. These layers had permeability characteristics ranging from nearly impermeable clay layers to slightly permeable silty sand layers, respectively. Furthermore, the flow of each aquifer was determined and flow characteristics were mapped (33:925).

Considering the contrast in the permeabilities of adjacent layers (i.e. a less permeable layer next to a more permeable one), and the groundwater flow characteristics, certain conclusions were drawn about the probable spread of contamination by way of groundwater flows. In a subsequent article, John Deegan, Jr. stated that:

> On the basis of these findings, [permeability coefficients and ground water flow

> characteristics] it was determined that unless the glacial till [one of the soil types identified by the geological study] was breached during excavation, no contamination of the bedrock aquifer directly attributable to Love Canal was likely [12:422].

This hypothesis was borne out by water and soil testing data analyzed for various locations around the contamination site, thereby indicating the value of the hydrogeological study:

> The contaminated shallow-system groundwater was confined to the actual landfill. In particular, clear evidence of the contamination was found only within Ring 1 of the canal area (outside the area bounded by the containment system) [12:422].

Although serious in nature, the Love Canal landfill contamination was contained and was not spreading to any great extent.

This type of analysis becomes very important when attempting to follow a possible contamination stream. Without the ability to draw such conclusions much time, effort, and money would be wasted while seeking the ends of a contamination stream without an adequate identification plan.

Scope of the Research Topic

Research into this topic involved a review of technical journals and literature concerned with research and evaluation of pollution and its dangerous or hazardous effects on the environment and, more specifically, how it is transported by groundwater. It also includes a review of defense program literature and guidance, namely the IRP and associated guidance, aimed at correcting Air Force pollution and hazardous waste contamination sites.

Research Objectives

The selection of appropriate investigative strategy is paramount to the effective performance of the Remedial Action at a contamination site. The following research objectives will assist in identifying such strategies:

1. Identify current strategies and technologies that are being employed by the Air Force and civilian environmental engineers to define contaminated soil and groundwater.

- How are they being used?
- What is the size and scope of the contaminated area being investigated?

2. Identify successful and less than successful efforts to accomplish contamination delineation and identify the reasons for success or failure.

- How are they efficient/inefficient?
- How are they accurate/inaccurate?
- Why are they cost-effective/ineffective?
- What were the key decisions made that lead to success/failure?

3. Identify how environmental programs are managed and administered.

- How are offices manned?
- What are relationships with regulators like?

Summary

In order to satisfy political, social and environmental needs the Federal Government, DoD and the Air Force have developed and implemented the Installation Restoration Program. Utilizing appropriate investigative and reclamation procedures, the goal of cleaning up the environment can be achieved. Without them, the program may become an endless financial drain providing little or no benefit to public health or environmental recovery.

This research is intended to provide information regarding the identification, selection, and implementation of such investigative procedures. It is an effort to help decrease unnecessary spending and increase environmental restoration effectiveness.

II. Literature Review

Background

Literature regarding the identification and mapping of groundwater and its movement has increased considerably over the past several years. Increased public awareness of groundwater aquifer problems has driven researchers to develop cost-effective, accurate and reliable means for determining the extent of man's and nature's effects on aquifers. Government publications, including General Accounting Office (GAO) reports concerning the IRP and hazardous waste issues plus various IRP reports from Air Force bases across the country were reviewed. Literature concentrating on current technologies of groundwater aquifer identification, quantification, and movement were also reviewed.

Today's IRP

As tne IRP was originally established to operate, the first phase (Phase I or the Preliminary Assessment (PA)) is conducted under the watchful eye of the Base Civil Engineer or his representative. Typically, a private contractor is hired to conduct the survey.

Until recently (up to two years ago), once Phase I (PA) was completed, Base Civil Engineering would hand the study off to the Surgeon General (SG) Bioenvironmental Engineer's office so they could monitor the second phase of the process

(Phase II or Remedial Investigation (RI)). Here the Air Force Occupational and Environmental Health Laboratory (AF OEHL) generally had the responsibility to oversee a new contractor who performed site work that was intended to confirm the existence and quantity of contamination at sites identified by the PA (13:Appendix L).

The Phase II process was often drawn out and many times proved inconclusive. Reports that were intended to provide information suitable for making Remedial Action Plan (RAP) design decisions included vague statements regarding contamination delineation or groundwater flow characteristics. Most included recommendations for further study prior to selecting methods for remediation (19).

Though SG has been substantially removed from the process, leaving the BCE to oversee the entire IRP from start to finish, many existing programs still rely on data and documents produced under the original concept (24).

The United States General Accounting Office (GAO) has been called in on numerous occasions to investigate the IRP at specific installations. For instance at McClellan AFB, CA, the GAO reported:

> GAO's evaluation of the Air Forces's efforts to control contamination at McClellan [AFB, CA] disclosed that
> -- more work may be warranted to substantiate the safety of McClellan's drinking water.
> -- the Phase II study did not adequately determine the magnitude and extent of the base's environmental contamination problem, and did not make recommendations to clean up the environment [46:i-ii].

Contractors retained to perform Feasibility Studies (FS) and design Remedial Action Plans (RAPs) are forced either to draw drastic assumptions or they must proceed to further delineate and quantify contaminated regions. Mr. Michael Grenko, Environmental Coordinator, McChord AFB, WA. commented:

> We have conducted feasibility studies in Area A [McChord's POL tank farm area] for the purpose of designing clean-up proposals but have found that we needed more quantification [of ground water and contamination] in the area to make an accurate assessment of the contamination before we can even begin a design. We have regressed back into remedial investigation [19].

In many of these cases the funds provided for feasibility study and remedial action planning are fully expended for quantification. "We used up all of the funds provided within the contract [to design the RAP] before we even found out how big the problem was. We cancelled additional contracts in the FS stage to concentrate on quantification [of ground water movements and contamination]" (19), stated Mr. Grenko.

Another problem arises when sites are not initially identified through Discovery and Notification (D & N) or the PA. Because investigations often begin with little or no existing technical information some contamination sources may be overlooked. Left undetected and untreated, contaminants from these sites may pose problems with recontamination of treated sites. In a GAO report on Tinker AFB, OK, it was noted:

> The [Army] Corps of Engineers plans to perform a complete investigation of the streams on [Tinker Air Force] base and, according to Oklahoma Water Resources Board officials, it is very important that the source of contamination in these streams be cleaned up before any further cleanup actions are taken [in the streams]. If the contamination going to the streams is not stopped, the streams might have to be cleaned more than once. For example, the cost of dredging the visible contamination from a relatively small area in Soldier Creek [on Tinker AFB] was $2.3 million, but core samples taken after the dredging continue to show high levels of heavy metals [47:19].

It is obvious that serious shortfalls are present in the existing Air Force IRP, particularly, within the identification and quantification stages. For this reason, it is important to review and understand the current technology available for groundwater and environmental evaluation and monitoring.

Groundwater Pathways and Contamination Transport

As previously mentioned, identifying groundwater transport pathways, capacities and velocities are pivotal aspects in quantifying contamination and delineating its boundaries:

> Once aquifers in the study area are identified and geologic materials surrounding them are described, the flow of groundwater through the aquifers, from areas of recharge to areas of discharge, should be determined. Determining the direction and rate of groundwater flow is important, since this information allows the fate of contaminants introduced to the aquifer to be predicted and the threats that the contamination poses to groundwater users down-gradient from pollution sources to be assessed [23:65-66].

In many cases, nontechnical factors influence environmental decision-making to a greater degree than site-specific technical data. Community sensitivity and cost-recovery litigation requirements often overshadow the inherent need for quality technical data. As a result, studies driven by politics or financial considerations are often supported by less reliable 'site-by-site' strategies. Results from these investigations are often of limited value:

> The data bases resulting from this investigative methodology [where contaminated sites are investigated individually as isolated entities without investigating groundwater flow characteristics on a broader scale] typically do not adequately support detailed analysis of the predominant contaminant transport mechanisms, and, as such, are of limited value in estimating potential exposure concentrations or in evaluating and designing effective remedial actions [16:1495].

<u>Contamination Plume Delineation</u>. Traditional RI methodologies begin with the establishment of monitoring wells or stations and subsequent water quality analysis of samples taken from these stations. This strategy is, ". . . aimed at defining the type, magnitude, and spatial and temporal distribution of contamination" (16:1496).

Using traditional strategy, monitoring points are usually selected based only on surface conditions and background information:

> . . . the location of these monitoring points is generally predicted on the general knowledge of site conditions derived from topographic gradients, aerial surveys, historical accounts of disposal activities, and a variable amount of site-specific technical data. . . Frequently the results of these initial sampling episodes reveal that the contamination has migrated beyond the initial limits of the study area and/or the concentration gradients cannot be decisively interpreted within the constraints of the existing data base. In either case, the typical response to this situation has

been to establish additional sampling stations [ref--red to as an iterative 'drilling event'] and collect and analyze more environmental samples [16:1497].

This traditional strategy, in many cases, deteriorates into a 'plume chase' and the goal of defining contamination quantification shifts to ". . . locating the leading edge of the plume" (16:1497). This approach is referred to as the 'Plume Delineation' method.

Transport Quantification. An alternative to Plume Delineation is to identify and quantify groundwater flow transport pathways and mechanisms. This strategy, called Transport Quantification, postpones environmental sampling and analysis until groundwater transport characteristics are adequately evaluated (16:1497).

Jack Dowden of Waste Management of North America and Larry Johnson of Foth & Van Dyke and Associates compare Plume Delineation versus Transport Quantification to wildcatting versus geologic exploration in the petroleum industry. They point out that, although wildcatters have been responsible for finding several major oil-fields, the success ratio and recovery percentages attained through geologic exploration far exceeds that of the wildcatters (16:1497).

The principle behind Transport Quantification is simple. Utilizing the same background data that was used in Plume Delineation, a conceptual model is developed along with identifying critical parameters of the area under investigation.

Geophysical techniques, which will be discussed later in this paper, help identify subsurface geological formations and changes in a non-destructive or nominally destructive manner.

Actual subsurface investigations are begun by implementing less expensive techniques aimed at defining groundwater transport pathways and mechanisms. Stratigraphic borings are made, piezometers for measuring groundwater depth and fluctuations are installed and data is collected.

Once sufficient data is obtained through this process and hydraulic parameters are defined, monitoring wells are placed at the most advantageous locations and samples are taken and analyzed (16:1499).

There are many advantages to the Transport Quantification approach. These advantages include time savings as the initial plan accounts for the identification and quantification of groundwater transport pathways and ultimately, the quantification of contaminants and their concentrations.

Plume Delineation attempts to quantify contamination in a phased or sequential approach which, by the nature of the process, generally involves considerably more time.

A second advantage of Transport Quantification is reduced costs of laboratory expenditures, shorter investigative durations, and minimal spurious data collection.

According to Dowden and Johnson, "The most important advantage of the Transport Quantification approach is that the resulting data base can be utilized to develop more accurate and realistic estimates of actual and potential exposure concentrations for input to the endangerment assessment" (16:1499).

Another view point was offered by Dr. Joseph Keely, of the Oregon Graduate Center. Dr. Keely asserts that if proper preliminary assessment is accomplished and surficial geological and hydrological characterization is thorough, monitoring and recovery well placement can be performed in closer proximity to contamination sources using the surficial characterization to guide well placement. He does not feel it is necessary to perform 'checker board' drilling across a large area to identify contamination sources. It does, however, take a trained expert to analyze data from water samples, well drill cuttings, and well pumping operations to gain an accurate picture of the site (26).

Well placement and monitoring should initially be confined to an area within a few thousand feet of the known contamination source, according to Dr. Keely. The predominant means for determining groundwater flow characteristics and transport mechanisms is to use stress pumping and evaluate draw down at wells placed within the study region (26).

The extent that groundwater characteristics at monitoring wells placed in proximity to the pumping well are affected by the pumping can help determine the hydraulic conductivity or the ability of local geology to transmit groundwater and, with it, contamination (26).

Dr. Keely recommends a phased well placement approach wherein information from sequential phases of wells drives the placement of subsequent wells. By conducting a thorough investigation along these lines, Dr. Keely believes a lot of unnecessary well placement and sampling can be avoided (26).

Along with flow characterization, chemical analysis is performed on samples of well water at the source well in addition to other wells in proximity to the source. Together, results from these tests will help define and quantify contamination (26).

Dr. Keely did not discount the value of complete installation-wide or transport quantification geological and groundwater characterization. He did, however, recommend against using that strategy as a means of identifying contamination sources. He again emphasized that thorough surficial investigation would reduce the number of wells required to characterize the installation (26).

Current Technology

To conduct an adequate environmental investigation accurate data about aquifers and their geology must be obtained. Some of the required data is available from existing sources but much data will have to be collected to completely characterize the groundwater:

> Different types of information must be collected in order to characterize aquifers, groundwater flow, and groundwater quality in a community. The specific type and form of information will need to be determined by a trained consultant who is familiar with the needs of the planning process. . . . The first task of conducting hydrogeologic studies is to identify and describe the aquifers present in the study area. This is done by having the technical consultant examine the surficial and bedrock geology of the study area in order to locate the geologic formations that comprise the aquifers and their confining layers. . . . Data used to develope aquifer maps comes from previously published reports, well logs submitted by drillers, or other existing sources. A substantial number of statewide maps have been developed by state geological and water surveys, and by the U.S. Geological Survey. . . . Much of this information, however, will not be detailed enough for planning at a county or municipal [or base level] scale. Additional data will usually have to be available [23:58-59].

For the reasons stated above, it is necessary to be familiar with and utilize various groundwater data gathering and study techniques.

Much of the literature deals with determining the volume of water that exists in aquifers that are accessible using today's technology. Other literature attempts to identify means of determining the existence and extent of contaminated groundwater, whether from man-induced pollutants or from natural causes, so that clean-up activities may be undertaken to restore the water to an environmentally safe standard.

This review takes a look at several of the more prominent methodologies of geological and hydrogeological investigation currently in use. The three general categories of investigation are:

1. Surficial and Geophysical Surveys.
2. Mathematical and Computer Modeling.
3. Placement and Use of Sampling Wells.

Each of these methods in and of themselves would be of limited use to the Environmental Manager. A combination of these methods is by far the most efficient and effective means for arriving at a complete and accurate aquifer mapping. Richard W. Schowengerdt of International Technology Inc stated:

> Although ground water cannot be seen on the earth's surface, a variety of surface techniques such as geophysics and vapor surveys have potential to provide information pertaining to ground water occurrence and quality characteristics. Surface investigations do not provide a complete hydrogeologic picture; however, these methods are significantly less costly [than well drilling and monitoring technologies] and do provide a reconnaissance level site specific definition to guide later activities [40:41].

Likewise, mathematical and computer modeling techniques must be used and incorporated into a complete groundwater aquifer identification and mapping process. As with any model, it is necessary to provide complete and accurate data from which the model input parameters may be derived. Known data is also required to validate the model to ensure it accurately depicts the groundwater movement.

The only true means for verifying subsurface geological and hydrogeological characteristics is to perform core sampling, groundwater monitoring well installation, and water sampling. Unfortunately, this method is extremely costly and is usually limited to use when confirmation information is required to substantiate data achieved through the other speculative techniques. Mr. Schowengerdt stated:

> Drilling procedures are often one of the most expensive aspects of a ground water investigation. Drilling is the only method which directly accesses the ground water resource, with the exception of spring seep development. If surficial techniques are carefully designed and executed, drilling can be minimized to only essential, supplemental portions of the study. Drilling can further be minimized by the multiple use of bore holes for geologic interpretations (coring), aquifer testing (well tests), water quality sampling, and as a product recovery well [for cleanup] [40:44].

Surficial and Geophysical Surveys. Dr. Keely, a professor at the Oregon Graduate Center, expressed strong affirmation of surficial investigative techniques. Working as a consultant for the US EPA, Dr. Keely has observed many environmental studies and has developed a methodology for site investigations that details a step-by-step process for characterization. His strategy relies very heavily on surficial investigations, interviews with local personnel and combining findings from these methods with other existing information on regional characteristics during the early stages of the investigation (26).

Dr. Keely stated, "I begin by looking at the gross setting of the problem area. Whether it's an arid or a humid setting makes a big difference. This usually implies, for example, that the unsaturated zone is going to be relatively thick if it's an arid setting, whereas it's going to be a relatively short distance to the water table if you are in a humid setting" (26).

Dr. Keely went on to discuss the impact that regional structural features such as valleys, hills, streams, rivers, mountains, and so forth have on local conditions (24). Based on the type of stream activities in the areas conclusions can be drawn:

> Looking for depositional trends would be the biggest deal. What types of streams and tributary orientations are there in the valley. Is it an isolated meandering stream that works its way through most of the valley where the site is? If it is, than you can expect a whole lot of cross-cutting of clays and that kind of a thing. There will be a lot more of a random distribution [of groundwater] [26].

Dr. Keely commented this depth of analysis on the regional level is necessary to better understand what is most likely going on in localized areas. Techniques he employs on the local level prior to drilling are basic and established but often overlooked:

> I like to use the old field hydrology ways of looking for things. You know, look for phreatophytes, look for willows and ash and stands like that to see where, in fact, there may either be perched waters or there may be seepage from an aquifer fairly close to the surface [26].

To assist in identifying probable contamination sources, Dr. Keely recommends interviewing personnel who have worked at installations for a number of years to obtain information on possible past practices that might have led to contamination (26). The interview process is included as part of the IRP and is conducted under the Preliminary Assessment or Phase I.

Once regional and local surface conditions have been adequately characterized and preliminary assessment interviews are complete, Dr. Keely indicated some surface geophysics can be performed, such as ground penetrating radar and electromagnetics to identify depths and changes of soil strata. He stated that these techniques are excellent for identifying unrecorded utilities or other disturbances introduced into the natural geology that may act as conductors or pathways for contaminants to migrate along. However, true site soil and groundwater characteristics must be obtained through bore hole placement and analysis (26).

Why Dr. Keely does not emphatically suggest the use of surface geophysical techniques is he feels the data achieved through these techniques is very speculative. He stated that, in order to adequately verify the findings of geophysical studies, bore holes must be placed to accurately characterize strata and calibrate the geophysical readings. "Once you've drilled enough bore holes to really do a great job of calibrating your soundings, you damn near know every thing you need to know" (26).

Within the geophysical technology there exists a variety of surficial techniques. Mr. Schowengerdt presented several of the more common ones in his paper:

Geomagnetics (GM). Geomagnetics involves the measurement of a magnetic field induced by site-specific conditions. GM is often employed to locate metallic objects that have been buried beneath the surface such as waste drums. GM is also capable of identifying changes in geological characteristics caused by natural phenomenon such as fault activity or those caused by man through excavation or fill practices. A grid of equipotential magnetic contour lines that reveal geological characteristics are plotted from the data achieved through the GM process (40:41).

Electromagnetics (EM). Electromagnetics measures differential electromagnetic conductivity between transmitter and receiver coils which are located approximately 12 feet apart. EM surveys are most useful for differentiating between conductive and nonconductive regions. Regions saturated by landfill leachate can be accurately identified using EM and a contour grid map, similar to that used in GM, to show iso-conductivities (40:42).

Electrical Resistivity (ER). Electrical Resistivity is very much like EM in that differential electrical resistivity measurements are made between groups of electrodes embedded into the surface of the ground. ER will yield similar contour maps but is limited in its application to regions which exhibit moist surficial conditions (40:42).

Ground Probing Radar (GPR). Ground Probing or Ground Penetrating Radar detects changes in subsurface geological conditions by sending pulses of FM frequency waves from a source emitter and graphically recording the return pulses. The depth of penetration of the radar is governed by the composition of the geological material. The results of GPR tests are then compared to known saturated and unsaturated lithologic responses (40:42).

Soil Gas or Vapor Surveys. Soil Gas or Vapor Surveys (Sniffers) are widely used in identifying contamination boundaries of petroleum and organic solvent compounds commonly referred to as volatile organic compounds or VOCs:

> When volatile organic compounds are involved in ground water contamination, dissolved or floating product plumes occur. A component of these contaminants are present as a vapor or soil gas phase which indicates the plume's spatial extent. Portable photoionization meters or "sniffers" can detect these vapors through shallow bore holes. As with the geophysical methods, a sampling grid is marked in the study area. A bore hole is drilled within 1-2 feet of the plume and immediately "sniffed". The peak concentration is recorded at each borehole (sampling point) to be contoured later. Vapor surveys have proven to be especially effective in delineating gasoline and diesel fuel plumes, allowing recovery wells to be located in the most effective locations [40:43].

Since much of the contamination that exists on Air Force installations is VOC in nature from leaks at POL tank farms, depot maintenance cleaning practices and various types of fuel spills, soil gas analysis (sniffing) can be a valuable tool for effectively identifying locations for sampling wells.

Remote Imagery and Aerial Photography. Remote Imagery and Aerial Photography in many cases can be used to obtain useful information about groundwater conditions. Through analysis of variations of surface conditions such as changes in color, terrain, vegetation, and geology the skilled technician is able to draw conclusions regarding likely subsurface conditions. These conditions can then be verified by installing wells at locations determined through the analysis. Well placement is minimized and investigation costs are likewise reduced (40:43).

Summary of Surficial and Geophysical Techniques. Surficial geological and geohydrological observation reports compiled as a result of employing these techniques identify many subsurface characteristics. Density changes in soil or rock formations are evident. Underground ridges and valleys that may define aquifer boundaries are often identifiable. Surface characteristics such as location of surface waters and geological variations are very revealing of what subsurface hydrology and geology is like.

According to Dr. Keely, review of old aerial photographs which could reveal the natural, undisturbed characteristics of the site or locations of old landfills or industrial waste areas are also great sources of local information. Blueprints of underground utilities are valuable sources but often are missing information that was not recorded after utility work was completed (26).

These techniques, however useful, investigate only the physical (structural) and visual characteristics of the location under study. Conclusions drawn from study results only reveal what 'might exist.' Technicians can only draw conclusions based on past experience with little or no knowledge of what is truly the case at the location under study. Without substantiated evidence from soil boring samples at various points of the study region, geophysical information is without merit. Mr Schowengerdt pointed out, "Geophysical methods often lack detailed resolution and need to be supplemented by later subsurface investigation. Results provided by geophysical testing, however, allow for extensive spatial coverage at a reasonable cost" (40:41).

These techniques do provide valuable information for use in determining proper locations for sample well placement. The number and depth of wells can be better estimated if adequate geophysical studies have been completed.

Mathematical and Computer Modeling. There are literally dozens and dozens of mathematical and computer groundwater modeling and mapping techniques in use today. Many of these techniques are useful for estimating the recharge and discharge of an aquifer. Others map out flow characteristics or total capacities of the aquifer. Some consider two dimensional plans in vertical and horizontal directions while others consider multi-level aquifers. Dennis McLaughlin and William K. Johnson noted:

> Over the last few decades computerized groundwater models have moved from the research laboratory into the offices of consulting hydrologists and government planners. The wide accessibility of these models and the equipment needed to run them has brought about dramatic changes in the way groundwater studies are conducted. Computer modeling has undoubtedly helped to make water supply planning [and environmental assessments] more reliable [31:405].

Although so many models exist, one single model to evaluate all aspects of groundwater systems is lacking. Joaquin Andreu and Andres Sahuquillo write, "Planning a complex water resource system including ground and surface components entails taking many aspects into consideration (hydrological, technical, economic, legal, social, etc.). There is no single model capable of fully describing the system and all its interactions" (5:110).

Models have become very useful tools in groundwater mapping. They allow the technician to observe what water movements and transportation of contaminants might occur under various seasonal and other natural conditions. By simply adjusting parameters of the equation or program the entire computed aquifer can be reevaluated for the changed conditions.

For the most part, models are designed to give the water resource manager a reasonably accurate model to aid in management decisions. Yeou-Koung Tung commented, ". . . it seems that the use of a simple but representative groundwater model could be adequate in management problems. Furthermore, computational simplicity is an advantage of using a simple model to provide decision-makers with quick but relevant solutions to management problems" (45:3).

That is not to say that all models are designed for quick analysis. Many are very complex, requiring much reliable input data and many expert assumptions. A lack of necessary data or expertise can result in inaccurate model development and poor results. Tung stated:

> Like any other resource management, groundwater management is generally done in the environment where uncertainties exist. Uncertainty in groundwater management may be ascribed mainly to lack of perfect knowledge about an aquifer system, inherent variability of systems parameters and flow characteristics, and other factors such as cost and revenues of the project, engineering design, and operation of the system. As a result, the existence of uncertainties limits our capability to predict system behavior with definiteness under various management decisions [45:2].

Tung continued:

> In groundwater management, the selection of an appropriate model for analyzing cause-and-effect relationships of subsurface water flow [contamination transportation due to groundwater flow and fluctuation] is largely dependent on the budgetary condition and data availability of the groundwater system. . . . However, meaningful results can be generated only if there are sufficient amounts of data of good quality available [45:2].

In other words, if there is very little money in the budget or very little detailed data or knowledge about the specific aquifer available, it will be reflected in the results of the model and its findings.

All mathematical and computerized models require the technician to make certain assumptions about the location under consideration. In many cases these assumptions drive the very answers that are derived from the model. The interpretation of physical characteristics by different technicians can result in very different conclusions. Dennis McLaughlin and William K. Johnson conducted a study involving the results of three separate analyses of the same aquifer (the San Andres-Glorieta Aquifer in New Mexico) using the same evaluation model. The three analyses were conducted in the same year (1982) by competing groups that had different vested interest in the aquifer in question (31:410-411).

The first study was on behalf of a public utility firm that desired to pump water from the aquifer. Their analysis revealed no adverse consequences to the aquifer would result from the pumping.

The second study was conducted on behalf of a local existing water user. This analysis revealed that the utility company's pumping would, indeed, have an adverse effect on the aquifer's level and quality.

The final study was conducted on behalf of another local existing water user but was separate from the previous study and was accomplished by a different firm. This third study revealed different results than the two previous analyses. Like the second analysis, it concluded that the utility company's pumping would result in adverse aquifer effects.

McLaughlin and Johnson cite numerous reasons for the differing results of the three modeling processes. They state that:

> Important assumptions are required at every stage of the modeling process: when the model's equations are derived, when a solution procedure is selected, and when inputs are estimated. Many of these assumptions are ultimately based on subjective interpretations of limited amounts of ambiguous field data. Different interpretations lead, of course, to different predictions, making the modeling process more dependent on the judgment of the individual modeler than is generally recognized [31:405].

To decrease the occurrence of such problems associated with the modeling process, detailed data reflecting the characteristics of the aquifer must take the place of modeler assumptions.

> . . . models can be extremely useful. However, the limitations, potential sources of error, and misuse of groundwater models should also be noted. Models necessarily involve the simplification and abstraction of the real aquifer, . . . Errors can arise in matching the appropriate modeling techniques to the hydrologic situation; rounding errors and other sources of inaccuracy may also be inherent in the model itself. The most common source of error, however, arises from feeding insufficient or inaccurate data into the model. Additional hydrologic studies may be required, to collect more better information [sic], if initial results are unsatisfactory [23:89].

Mathematical and computer groundwater modeling, when employed properly and combined with appropriate meaningful data, can aid the Environmental Manager in making decisions regarding remedial actions. However, without adequate input data the results can be deceiving. McLaughlin and Johnson wrote, "Computer modeling is a powerful tool, but it needs to be used with discretion. In particular, the uncertainties associated with the modeling process should be recognized and honestly acknowledged" (31:405).

Environmental Expert and Decision Support Systems. Recently, advancements in environmental expert and decision support systems have also occurred. However, according to Judith M. Hushon of Roy M. Weston Inc. who performed a survey of Environmental Expert systems:

> . . . expert systems are starting to be used to recognize and manage environmental problems. In general, expert systems can be divided into a number of functional categories: planning, monitoring and control, instruction, interpretation, production, diagnosis and repair, and design. . . . no environmental systems were found that were devoted to monitoring and control, instruction, or design [21:838].

For the immediate future, it appears models designed for groundwater flow and utilization will have to suffice to assist in delineating groundwater contamination.

Sampling Well Placement. As previously mentioned, actual geological, hydrological and water quality data can only be derived through drilling wells, analyzing core samples, and sampling water for contaminants. This, again, is the most expensive part of the RI stage of the IRP. Every effort should be made to insure wells are properly placed and efficiently designed to provide the most complete and valuable information while remaining cost effective:

> It is the project engineer's responsibility to match the variables to the project needs, data integrity, and budget constraints. The construction of monitoring wells has only provided the conduits required to access the ground water resource for sampling and testing. All subsequent testing and the ultimate project success

> relies on the quality and location strategy of the monitoring well completions [40:46].

There are many types of well systems being employed today. Each type has its own strong points and weaknesses. Some well systems are designed merely to check depths of aquifers and require less care during installation while others, from which stratified core samples will be extracted and analyzed, require great care during drilling to insure core samples remain intact.

Likewise, finishing or casing methods vary in complexity and cost depending on the intended use of the well. Wells intended for sampling water suspected of containing VOCs require special casings that do not contain substances that will give positive VOC readings (40:45).

Geology must be carefully analyzed to insure proper case screening (the portion of the casing that will allow the passing of water from the aquifer into the well for sampling). Improperly screened wells may provide a vehicle permitting groundwater to flow from one aquifer to another, risking cross-contamination if one or the other aquifer contains impurities:

> Aquifers are often separated from one another by impermeable layers of rock or clay. Often several of these confining beds will occur below the ground creating a series of different aquifers, one below another. Where the aquifer has such a layer above it, it is called confined. Water in confined aquifers is under pressure, in some places resulting in artesian wells [wells that exude water under natural pressures]. . . . In some cases, even aquifers that are widely separated geographically may be connected to one another. Identifying such connections can be very

difficult, depending on expensive exploratory drilling. And, if this drilling is not carefully done, it can itself produce interconnections [9:55].

The overall geological setting must also be considered. Wells placed in areas that experience frequent geological disturbances (earthquakes) may ultimately produce the same cross contamination effects as those that are screened over multiple aquifers. As disturbances occur, well casings may split or sheer, thereby providing the vehicle for water transport. In these areas, wells should be kept to a minimum and be designed to withstand a reasonable seismic disturbance (18).

To insure the proper selection and application of wells, an understanding of the various types of wells available for installation is required. Numerous variations of each type exist and require a knowledgeable geologist/hydrologist familiar with the local conditions and available technology to make the final decision on which method to employ:

> Field supervision of the drill rig and crew is extremely important with final field decisions (such as drilling depth, speed, or use of additives) often affecting all subsequent data. Once the final drilling depth is determined, a monitoring well is generally constructed in the auger flights [lengths or sections]. Well completion decisions again may effect outcome of the investigation and require an experienced field engineer. Based on the properties observed during coring, the specific well design is determined in the field. Recalling the liability issue mentioned earlier and the need for representative data, well construction must provide the integrity required for the project. The open interval (slotted or screened section) of the well should correspond exactly to the zone to be tested and monitored. Wells completed across multiple hydrostratigraphic units [aquifers] are virtually useless. Thousands of wells have been installed which

lack this integrity and make data analysis difficult and indefensible [40:44-45].

This review is not intended to be all-inclusive but rather serves as an introduction, for the benefit of environmental managers, to several of the more popular methods of well drilling, development, finishing, and sampling. The review notes some of the advantages and disadvantages of the different well types:

> There is no ideal monitoring well installation method for all purposes, so one should consider specific conditions at a site before deciding which drilling and development methods to use. The most widely used drilling methods include air and mud rotary methods, the cable tool or percussion method, and augering. Common development techniques include air-lift, surge and bailing, and over pumping. Specialized techniques for installation of monitoring wells at hazardous waste sites have begun to evolve from these conventional installation methods [25:57].

<u>Mud Rotary Drilling</u>. Mud rotary drilling has been employed in all types of well drilling applications including water, gas, and oil. It is preferred because of its relatively fast (in excess of 100 feet per drilling day) drilling speed. This type of drilling was used during the early years of environmental studies, primarily at off-site drilling locations. It has fallen into disfavor due to problems introduced when the 'mud' used as a lubricant and sidewall stabilizer, contaminates the well, forcing the use of expensive finishing and purging techniques prior to commencing sampling (25:57).

In mud rotary drilling, the bit bores out a hole with a diameter in excess of the drilling rig shaft (Figure 3). Mud

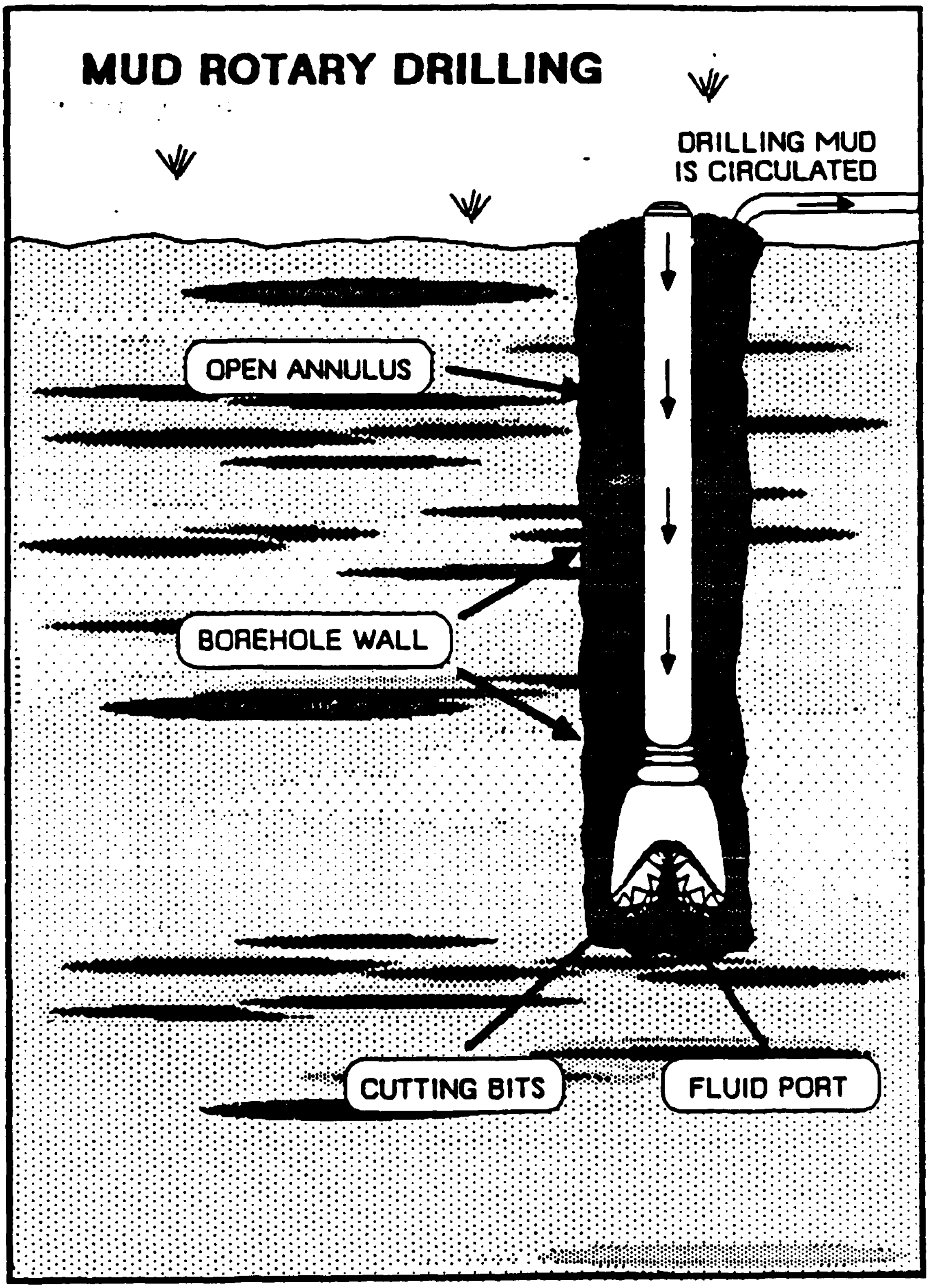

Figure 3. Cut-Away Sketch of Mud Rotary Drilling Method (25:59)

is injected down the shaft of the drill rig to lubricate drilling and shore well walls as mentioned earlier. Mud flows back up the sides of the borehole and exits, carrying cuttings with it. Substances contained in the mud, whether from the drilling process or from the borehole itself, may be deposited along the full length of the borehole, thus introducing possible cross contamination (25:58).

Air Rotary Drilling. Air rotary drilling is quite similar to mud rotary drilling. Air is used in lieu of mud and a temporary well casing is driven into the well shaft to shore up its walls (Figure 4). The risk of cross-contamination still exists to a reduced degree and if filtered (purified) air is used the risk is reduced even more. This type of drilling is limited to semi-consolidated and fully consolidated formations (25:58).

The greatest hazard of using the air rotary drilling technique is that hazardous material from the boring site may be transported up out of the well by the compressed air and will subject workers to high levels of contamination (11:58).

Cable Tool Drilling. Cable tool drilling employs the use of a heavy string of drilling tools suspended from a steel cable that are raised and dropped into the borehole to break up formations. Once sufficient progress has been made, the loosened material is removed from the hole and the process continues (25:61).

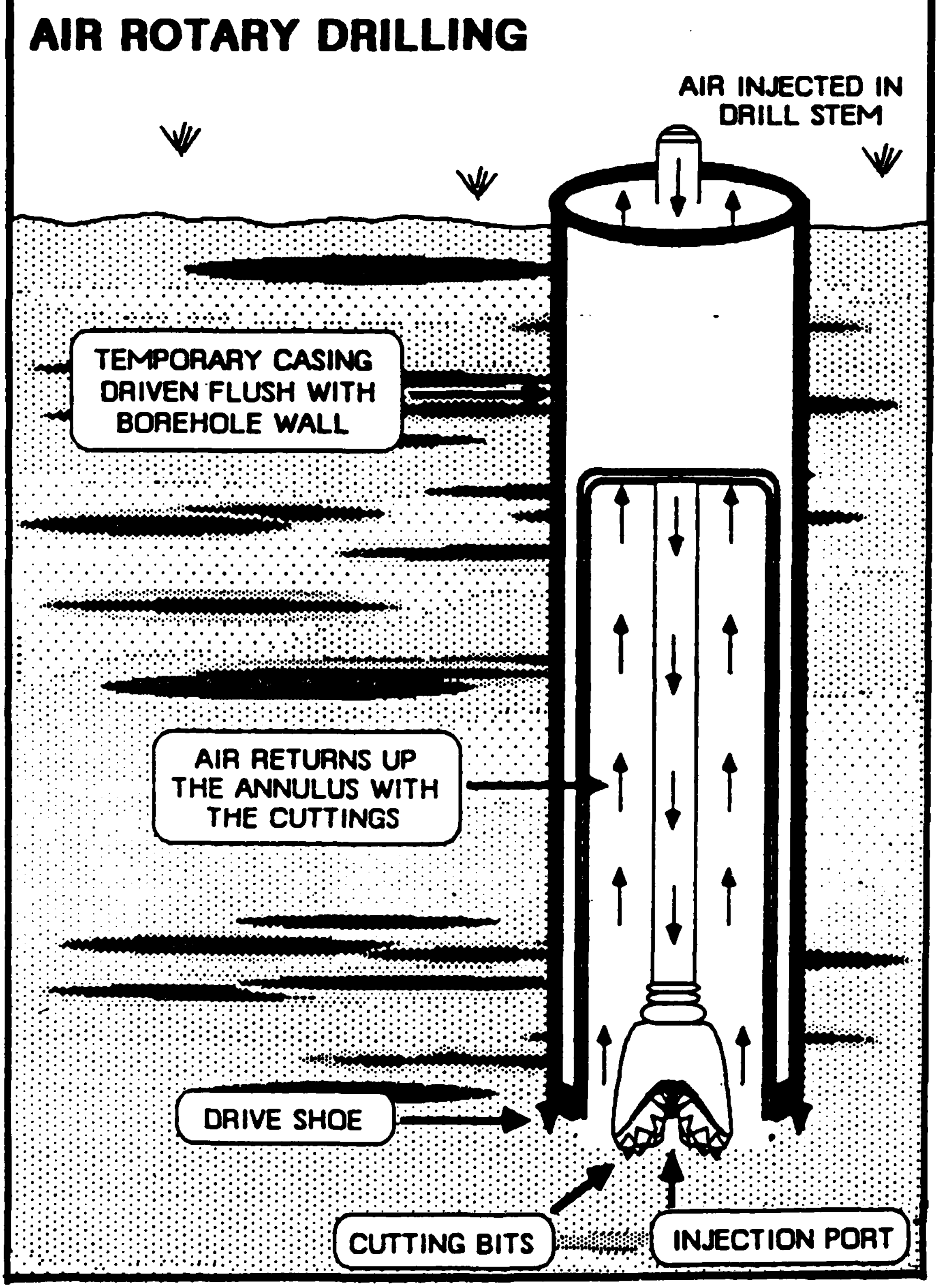

Figure 4. Cut-Away Sketch of Air Rotary Drilling Method (25:60)

A casing similar to the one used in air rotary drilling is driven into the borehole to shore up the well walls and aid in prevention of cross contamination (Figure 5).

This type of drilling is especially useful in areas where little is known about the geology or hydrology of the region. Because very little chance exists for contamination to occur during the process, relatively precise and accurate samples of water may be taken while drilling (25:61).

Hollow-Stem Augering. "Hollow-stem augering is fast and relatively inexpensive. Several hundred feet of borehole advanced per day in unconsolidated sediments is possible. The cost per foot of borehole is about $10-$15" (25:64).

Hollow-stem augering is preferred over rotary methods because it does not require boring fluids or injected air. Solid samples are retrieved by split-spooned samplers (a core sampling method) throughout the process. The center plug of the auger is removed when required drilling depth is reached leaving auger flights in place. Construction of the monitoring well can begin immediately (Figure 6) (25:64).

Potential drawbacks of hollow-stem augering include: possible cross contamination of upper layers of strata as core material is lifted by auger flights to the surface. This method cannot be used in hard formations for drilling and is limited to wells with a depth of only one hundred feet or so (25:64).

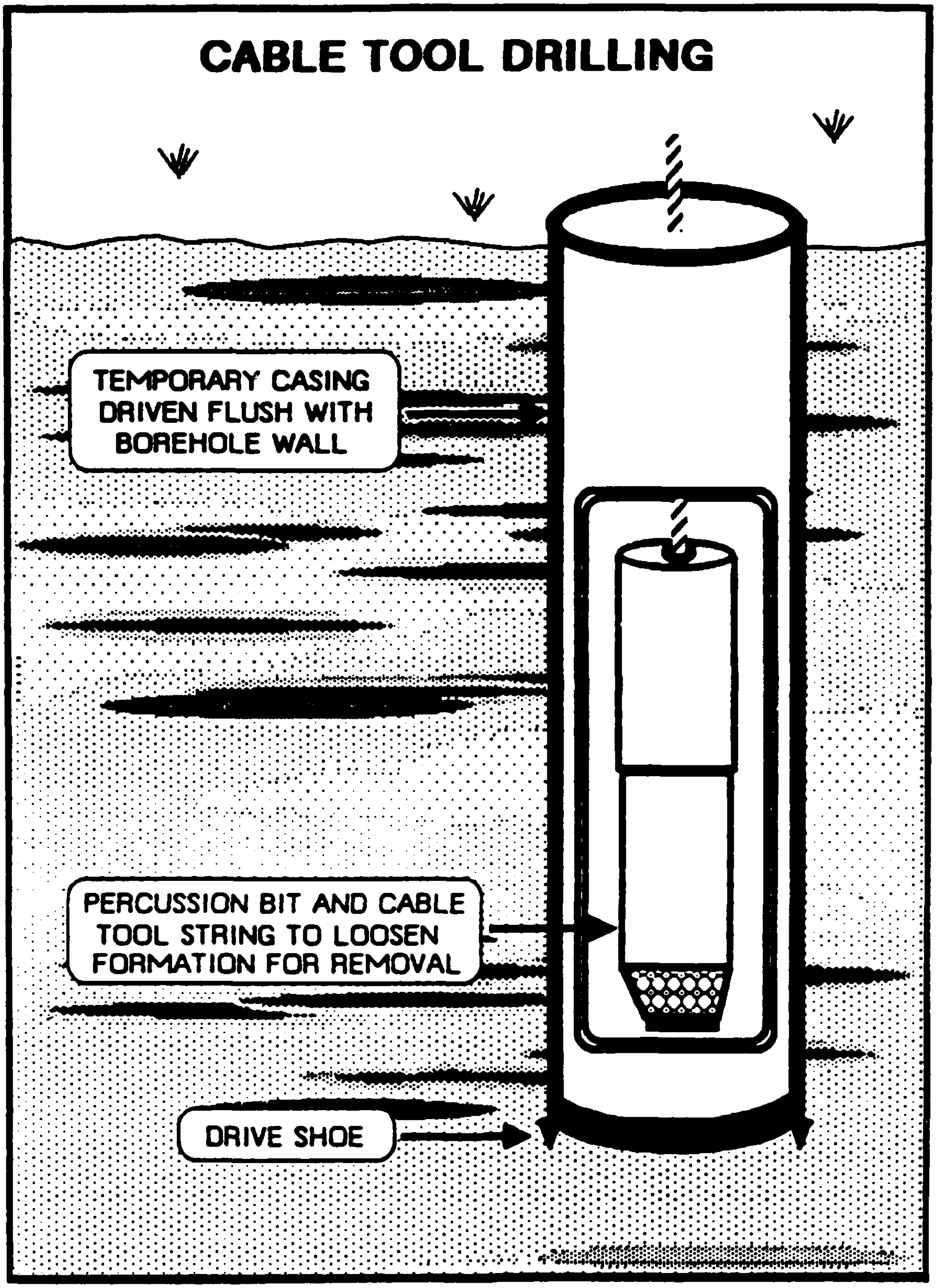

Figure 5. Cut-Away Sketch of Cable Tool Drilling Method (25:62)

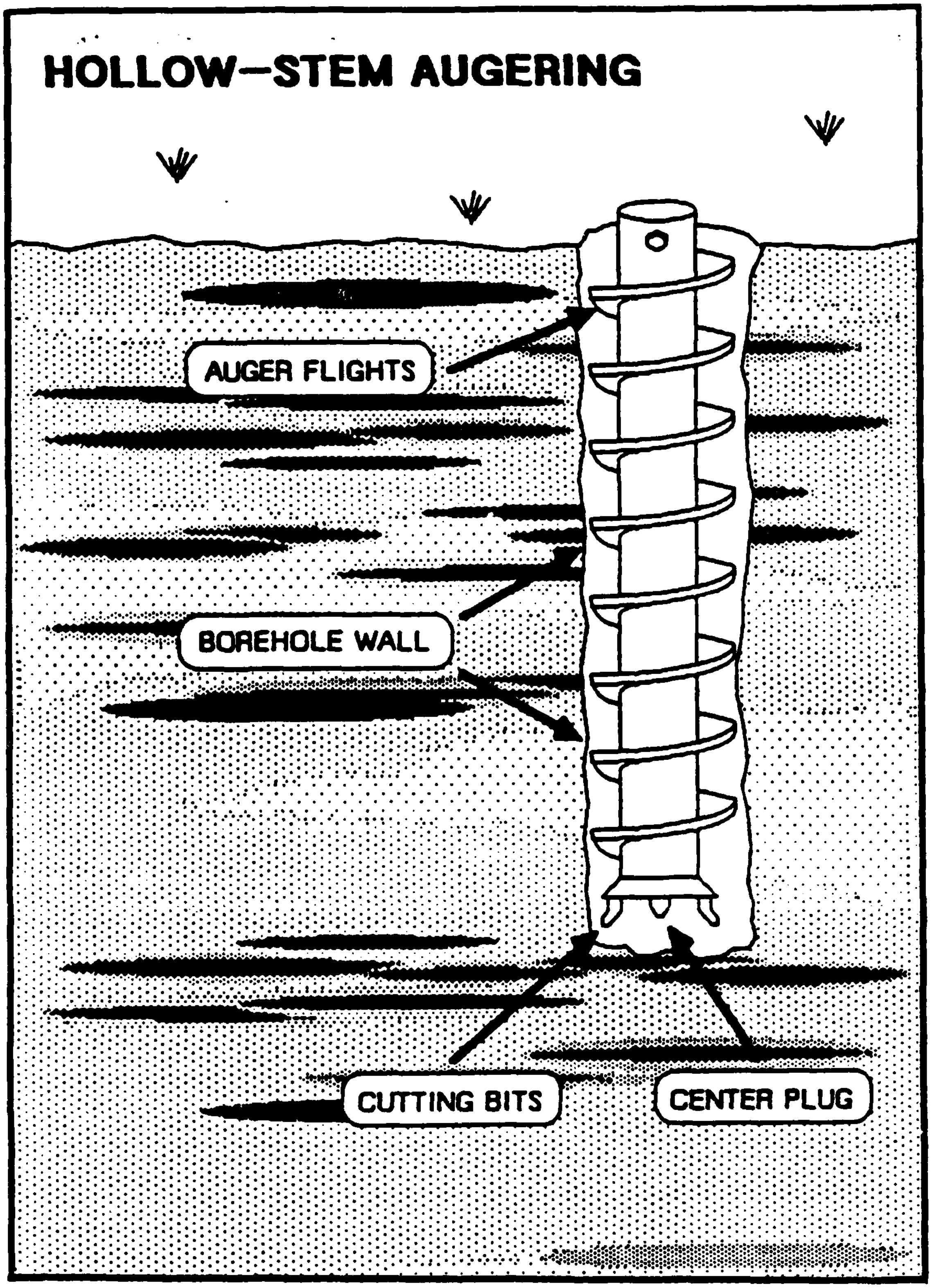

Figure 6. Cut-Away Sketch of Hollow-Stem Augering Method (25:65)

Hybrid Drilling Method. A hybrid drilling method has been introduced and tested in the recent past and has produced acceptable results. This method combines the use of the temporary well casing used in both the air rotary and cable tool methods with the drilling mechanism of the hollow-stem auger or mud rotary systems. "Augering is preferred because no foreign fluids need be introduced" (25:66). In both cases drilling progresses for a foot or two, the temporary casing is driven down to the new depth and the process continues until desired depth is achieved (Figure 7).

As with the other methods certain limitations exist. When using the hollow-stem auger, formations of large cobble or boulders may be impenetrable. This problem, however, can be over come in many cases by removing the center rod and bit of the auger and replacing them with a tri-cone bit (a bit that can cut through harder formations) until the strata of hard material is penetrated (25:64).

Well Finishing. In all drilling techniques the finishing of the well is just as important as the boring in well development. As mentioned earlier, a poorly finished well can cause more damage than good and can even result in cross-contamination or sample contamination from the casing material itself.

Mr. Schowengerdt states:

> Well screen . . . must be nonreactive with the suspected contaminants. Stainless steel, Teflon, and Bisphenol-A Epoxy represent examples of relatively nonreactive

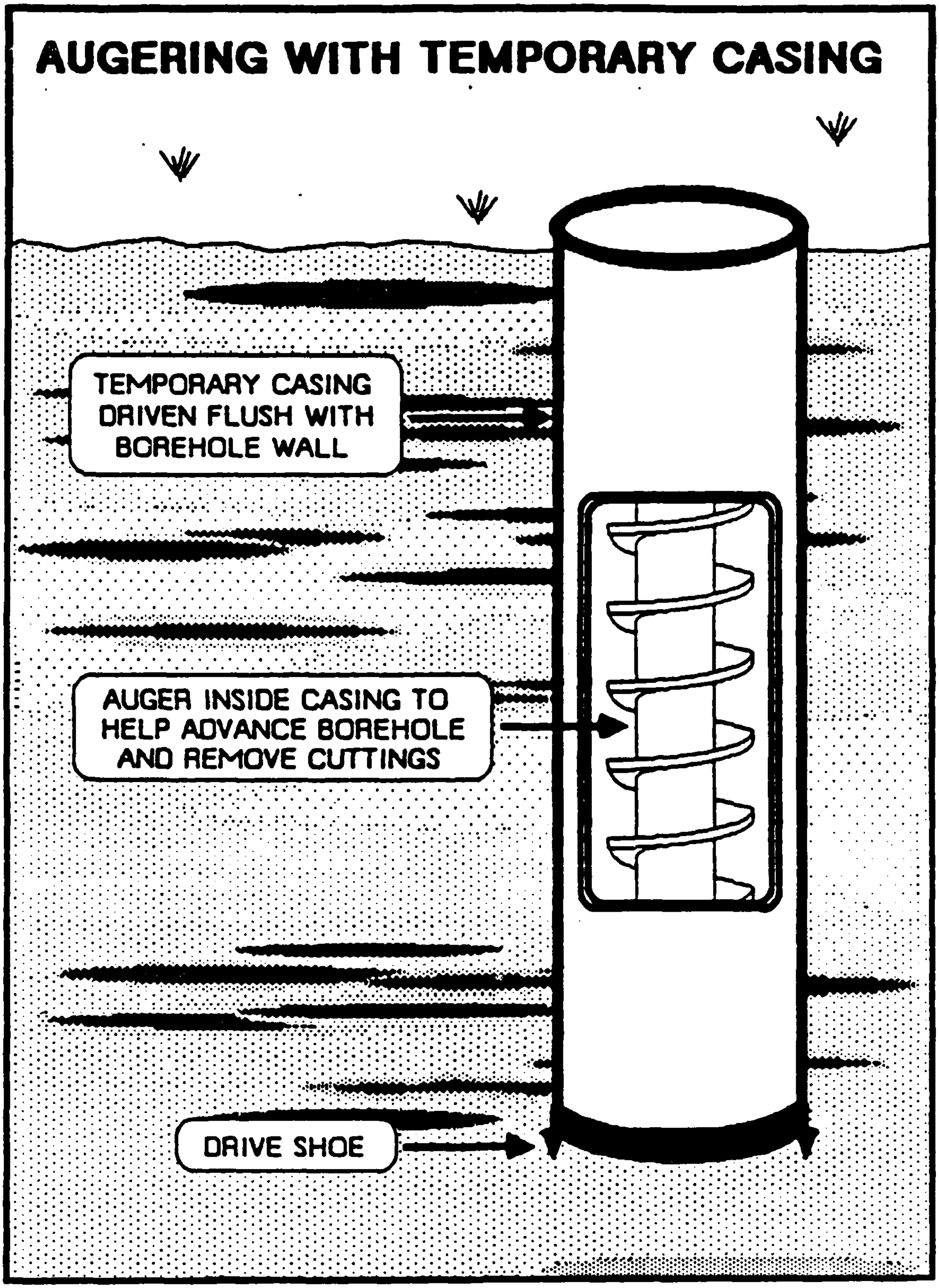

Figure 7. Cut-Away Sketch of a Hybrid Drilling Method Augering Within a Temporarily Driven Casing (25:67)

casing; whereas, PVC casing exhibits sorbent and leaching characteristics with many organic constituents [40:45].

Proper casing materials designed to meet the requirements of the sampling plan are a must.

Analysis of strata and aquifer locations and depths must be carefully performed to insure screening or slotting is placed in a way that will not cross contaminate aquifers while yielding the appropriate monitoring samples. This analysis will also aid in determining locations of additional wells if required.

Quality Assurance and Quality Control. Quality Assurance and Quality Control (QA/QC) are vital aspects of any environmental investigative strategy. In order to insure the accuracy and validity of an investigation, appropriate measures must be taken.

QA/QC plans detail purging and sampling techniques that will be employed to insure results of tests and analysis accurately reflect ambient groundwater makeup around the well. Without QA/QC plans, samples taken may not be indicative of actual in-situ groundwater conditions. Without addequate QA/QC, additional contaminants may be introduced by well placement and finishing techniques, casing deterioration or sampling methods. These additional contaminants may influence the constitution of the samples, thereby yielding false contaminant readings (40:39-40).

For additional information on QA/QC plans and requirements refer to U.S. EPA manual, "Data Quality Objectives for Remedial and Response Activities," produced by the US Government Printing Office, dated March 1987.

Summary. These are but a few of the many drilling techniques being used in industry today. They require very specialized knowledge to implement and analyze. This representative sample of well drilling methods, combined with data regarding geophysical analysis techniques and computer modeling, does give the reader a better understanding of how RI data is obtained and analyzed.

There are few shortcuts and circumventing any area of the RI process can produce a less-than-desirable outcome requiring further study, time delays, and added costs.

III. Methodology

Overview

In order to achieve the research objectives, a combination of methodologies was used. The first was the use of a qualitative survey which was accomplished by interviewing key personnel in the IRP process and others involved in environmental restoration activities.

Second, a review of the technical literature relating to current methods being used to identify contamination regions was accomplished.

The final methodology involved analysis of a case study at a selected base identified through the interview procedure to observe the IRP as it is implemented at the working level and to asses its effectiveness. McChord AFB (MAC), located near Tacoma, Washington, was selected as the case study base.

The results from the interviews, literature review and case study provide an illustration of various aspects and strategies of contamination identification, quantification, and transport within environmental restoration programs.

Methodology Justification

The methodology for conducting this research as described in the preceding section was selected based upon several compelling reasons.

The most important reason for conducting the research in this manner is that personal interviews allow the respondent to interject their individual expertise. By virtue of the vast number of different environmental problems and restoration strategies currently being employed today, expert opinion is by far the most practical and expeditious method of acquiring the needed information.

Second, the review of technical literature provides a look at how things are being accomplished within the civilian sector as well as IRP. Contamination region identification strategies not presently used by the Air Force or those not widely known by DoD and Air Force personnel were identified and brought forth for consideration.

Third, in the case study, it was important to give specific examples of how the IRP is actually undertaken at the working level. This is the point where administrative speculation and theory are tested. The case study provides valuable insight into the working level implementation of environmental strategies and the IRP.

Interview Format

A pre-interview letter was sent to key personnel at the headquarters level, introducing the researcher and informing respondents of the research topic and the reason for conducting the research. Subsequently, interviews were conducted telephonically in an unstructured, informal manner whenever possible. Some interviews were conducted in person as the situation permitted. All interviews began with a reintroduction of the caller and a brief reminder as to what the research was about.

Interviews were intended to acquire data on on-going IRP programs. Questions centered around the results of the Remedial Investigation (Phase II) and subsequent Feasibility Studies (Phase IVA). Phase II studies are intended to completely identify boundaries and quantities of contamination within a region. Selection of appropriate methods for remediation should be possible if investigation under Phase II is adequate.

Interviews were conducted within four Air Force major commands. Environmental branch representatives were contacted at headquarters and base level within the Strategic Air Command (SAC), Tactical Air Command (TAC), Military Airlift Command (MAC), and Air Force Logistics Command (AFLC).

Interviewees were asked several basic questions with regards to IRP contamination region identification, RAP and cleanup operations over the past several years, focusing on:

1. Current staffing at installation and command levels with respect to environmental practices.

2. Whether existing programs at installations or within commands were effective in quantifying and delineating contamination, thereby promoting transition into feasibility studies and remedial activities.

3. How other factors, such as community interest, regulator monitoring and intervention, technical training, and communication, affect the administration and effectiveness of the program.

4. Any overwhelming successes or failures at an installation or within a command and what reasons were attributed to the success or failure.

These four broad question areas provided the major portion of information required to meet the research objectives at this level. Beyond these structured questions, the interviewees were encouraged to interject any and all information they felt was relevant to the issue.

Observations and documentation of Installation Restoration Programs at several locations were performed. The emphasis in this stage of the research was to gain a complete picture of the effectiveness of the chosen strategy for the IRP regarding identification or remediation. Comments on community reaction and involvement in IRP activities were also solicited in an attempt to identify how community involvement may help, hinder or sway the IRP process.

The AF Occupational and Environmental Health Laboratory (AF OEHL) and civilian contractors involved in IRP investigations and designs were consulted for technical input regarding their experiences in environmental restoration programs.

Air Staff personnel were contacted for overall IRP financing information and the 'Air Force' point of view regarding the IRP. The Air Force Engineering and Services Center was contacted to gain insight into new IRP strategies and technologies being pursued.

IV. Analysis and Results

Introduction

In performing the analysis of data collected from interviews and literature, it became clear that four main factors are involved in administering an effective environmental restoration program or IRP. First, local geological and groundwater characteristics, along with sources and types of contamination, must be known and understood to effectively manage an environmental restoration program. This involves the proper selection of investigative strategies to achieve the desired results.

Second, staffing, at all levels, with personnel technically oriented in geological, hydrological and environmental disciplines, is essential in the management of these programs. Without such personnel on staff to technically administer, monitor, and report investigative proceedings, there is little chance accurate geological and groundwater surveys can be conducted, nor will information gathered during those surveys be communicated accurately or completely to those with a need to know.

Third, preeminent top level managerial emphasis must be placed on the program. Support and assistance from top level managers, from installation level up through the Pentagon and Congress, is necessary to insure the IRP receives appropriate funding and consideration.

Fourth and closely related to the management issue, there must be program continuity and information transfer. In the past, gaps have existed between installations, commands and services. Under the AF four-phased program, duties were split between Civil Engineering and the SG Bioenvironmental Engineer. In many cases, little program interface or communication existed between the two agencies.

Geological and Groundwater Characterization

Selection of the appropriate investigative strategy to adequately characterize the geological and hydrogeological setting, as well as the probable contamination source and chemical make-up, are essential. Thousands, even millions of dollars can be needlessly invested while pursuing an inappropriate strategy or through unnecessary analysis of contaminant constituents.

Without exception, all persons interviewed agreed that the use of surficial techniques, to varying degrees, was essential in characterizing an installation and for determining location of piezometric, monitoring and sampling wells.

With only one exception, from the program manager at a base which exhibits unique hydrologic conditions, all persons interviewed believed that complete geological, hydrological, and hydrogeological surveys would be of use in quantifying and delineating contamination plumes and transfer mechanisms.

Surficial Characterization. Although great emphasis was placed on surficial geological characterization by Dr. Joseph Keely (26), at many installations little was known about these processes undertaken as part of the IRP. Several respondents commented that they suspected surficial techniques had been used during the Phase I records search and Phase II remedial investigations. Few respondents, however, were aware of any benefit the results had provided in characterizing groundwater flow or in determining monitoring well locations, although they agreed, in principle, that such techniques would have been beneficial.

Captain Art Kamenski of the Air Force Occupational and Environmental Health Laboratory agreed with Dr. Keely regarding the usefulness of various geophysical techniques for identifying unrecorded underground utilities or buried objects in landfills. He did not feel geophysical techniques were altogether reliable for determining geological structures. He cited experiences where different geophysical techniques indicated conflicting subsurface conditions (24).

Mr. Michael Grenko also noted misleading information from geophysical studies conducted at the POL tank farm on McChord AFB. He commented that future geological studies will include as little geophysical work as possible. McChord's staff will rely mainly on results of monitoring well drill logs, pumping readings, sample analysis, and resulting analytical data (17).

One source stated that if geophysical techniques were used appropriately by contractors they could provide valuable data. He indicated a lack of understanding of the application of these techniques by contractors results in wasted time, money, and effort.

Geological and Hydrological Studies. The RI/FS at Kelly AFB, TX is now being conducted using a base-wide geological and groundwater characterization study. Until recently, Kelly AFB was being studied using the original four-phased IRP approach with little success (30).

This original Air Force strategy did not involve the characterization of the geological and hydrological setting beyond the boundaries of that site's contamination. This strategy generally requires that bases be investigated on a site-by-site basis. In limiting the data gathered to the specific contaminated site, results are limited to that site. If the contamination spreads beyond the perimeter of the initial study region or if additional contaminated sites are identified at a later date, further geological and hydrological study are required (30).

Although the basic terminology under which the IRP is administered and reported has been amended to follow the NCP process, it is also important to note, in most IRP programs in the Air Force, the original strategy that has been employed to run the program is still in use (29).

Mr. Robert Martian, the IRP Program Manager for Systems Acquisition - Air Logistics Command at Kelly AFB, TX indicated that Kelly AFB is currently involved in four independent RI/FS endeavors at this time. However, in each of those individual efforts, several sites have been combined into zones or regions for study rather than looking at each site independently:

> We're sort of broadening our concept as we go. We're trying to get whole zones and looking at the groundwater, it's hard to isolate site by site when you've got may be five or six sites adjacent to one another. . . What we've done so far [under the old phased approach] has not been satisfactory, it has not led us into [remedial actions] [sic]. . . we know we're contaminated, we know we're migrating some [contaminants], the groundwater shows it. But the remedial investigation to date has been too scanty to get into any kind of remedial action so now we're doing a full blown RI/FS and the way the statements of work are done I feel confident that when we come out we will have a plan of action. . . We feel like this should have been the first thing we did [base geological hydrological characterization] [30].

One of the products of the base-wide study will be a computerized groundwater model. Mr. Martian stated, "We want it (the base-wide characterization) for two reasons. We want it for plume tracking on our IRP sites. We also want it for future planning so we don't do something dumb in the future such as we've done in the past" (30).

Mr. William Metz, IRP Program Manager for the 90th Combat Support Group, F.E. Warren AFB, WY (SAC) presented the strongest case for conducting complete geological and hydrological studies during the initial phase of the IRP. He explained that under the original four-phased strategy, the draft Phase II report identified additional contamination problems beyond those identified in the Phase I records search at F.E. Warren AFB (35).

When asked to discus Phase II efforts Mr. Metz commented:

> We are doing additional study now. We got our draft report [Phase II draft] and it was lacking in getting a good definition [of groundwater characteristics and contamination] so we are going in to do additional work. Part of that was because the initial Phase II that was done out here found more problems rather than giving us a lot of answers [35].

Mr. Metz also stated:

> One of the things we would have done differently [than was done under the original-phased approach] would be to go in on a larger scale investigation. . . . What we had done initially was we concentrated on known IRP sites [identified in Phase I] and focused our investigation around those known IRP sites. We did not get a comprehensive coverage of the southern part of the base. . . . That left a couple of holes in the coverage of the groundwater in the southern part of the base as well as [sic] we were focusing on known problems and when other indications came up in the groundwater, we had to go back and do this additional investigation. We were trying to cut the costs as much as we could and we ended up not being able to do that [35].

Once the environmental staff realized the extent of the problem at F.E. Warren AFB, a program was initiated to characterize the shallow groundwater aquifer. Mr. Metz commented that approximately 100 piezometric borings were placed in the shallow aquifer and groundwater profiles were mapped. Mr. Metz went on to say that the complete groundwater and geology characterization of F.E. Warren's shallow aquifer has aided his office in administering the IRP. He said, "It has been very useful in the placement of wells and I think it allows you to reduce your total number of wells by knowing the characteristics of the groundwater. And also allows you to limit your sampling parameters to the ones that are necessary for particular areas" (35).

Mr. Metz estimated the number of wells placed in the F.E. Warren IRP effort could have been reduced by as much as 50 percent had the characterization strategy been implemented from the start of the IRP. He further estimated that since the characterization study was performed, F.E. Warren may have saved close to $100 thousand in investigation costs for the southern end of the base while performing the additional work identified earlier (35).

Mr. Metz commented:

> MAJCOMs are reluctant to pay for it [geological and groundwater characterization study] and we were able to convince them that it could end up saving them money if they went ahead and paid for it as part of the Phase II. . . . I think groundwater flow diagrams and things like that should be an automatic for all Phase II [RI] work. And it really should be done prior to jumping into the full bore Phase II investigations [35].

Another benefit of the characterization survey was that it identified additional contaminated sites (35).

One firm exception to performing installation wide characterization studies was offered by Mr. Allan Dalpais, IRP Program Manager for the 2849 Civil Engineering Squadron, Hill AFB, UT. Mr. Dalpais qualified his exception by pointing out that Hill AFB is located in an area with confined pockets of underground water that are not interconnected. He said the shallow, perched aquifers in the area often do not flow together and therefore need to be identified and studied on an individual basis (10).

Mr. Scott Mallette of the Environmental Management Office at Wright-Patterson AFB, OH (AFLC) stated that much of the information obtained in their IRP, prior to converting to the NCP format, lacked cohesiveness and analysis showed conflicting results. He said much of this data could be used as background information, but further evaluation of soil and groundwater must be accomplished before remedial activities could be undertaken (29).

Currently, Wright-Patterson is undergoing a USGS hydrogeological survey that will ultimately depict groundwater flow characteristics and will assist in quantifying and delineating groundwater contamination.

Mr. Stuart Reese, a geologist and Environmental Project Manager in the Wright-Patterson Environmental Management Office, said the USGS survey would include several new well clusters across the base. He further indicated some of the groundwater elevation wells would be designed and placed so they may be used as background sampling and monitoring wells. He indicated this strategy would provide the base with greater flexibility should requirements arise for contamination sampling in those areas in the future (39).

The cost of Wright-Patterson's USGS survey is $1.2 million which includes the upgrade of many of the wells as previously mentioned (39).

Officials at McChord AFB, WA (MAC) requested an installation wide survey, similar to the one being conducted at Wright-Patterson, as part of an upcoming RI/FS. The request was removed from the RI/FS work plan based on an estimated cost for the survey of nearly $2 million. McChord's Environmental Management Section did not seek a second estimate to try to reduce the cost of the survey (19).

Of the four major commands surveyed as part of this research, only AFLC has initiated installation wide geological and hydrologic characterization surveys. Table 2 illustrates this fact.

Table 2

Bases With Installation Wide Characterization Surveys

Command	Bases in Cmd With IRP	Bases W/Survey Or Developing Survey *	Est Avg Cost
AFLC	7	7	$1.0 Million
MAC	13	0	N/A
SAC	25	0	N/A
TAC	17	0	N/A

* some installations, such as F.E. Warren AFB, have conducted surveys on a reduced scale that are not classified as 'Installation-Wide.'

<u>Groundwater Aquifer Computer Modeling</u>. The use of groundwater aquifer modeling has gained wide spread use throughout the private sector for determining flow characteristics of domestic drinking water well fields and similar situations. However, this technique has not been

used extensively to aid in environmental restoration projects.

Capt James Aldrich, the Environmental Program Manager for the IRP at Headquarters AFLC, believes computer modeling is a viable tool for assisting in contamination plume tracking. AFLC feels so strongly about the technique, they are implementing full geological and hydrological studies, which include dynamic (computer) or static (manual) groundwater flow models, at all seven AFLC bases in the Continental United States (1).

Because of the extremely complex environmental problems existing at AFLC bases, environmental managers at all levels in AFLC determined full characterization studies and groundwater flow models were necessary to better control the IRP (1).

The typical AFLC base may have dozens of potentially contaminated sites which were not identified by Preliminary Assessment or the Phase I of the IRP. This can create problems as sites are later identified which require investigation and possibly remediation. With complete groundwater characterization and a flow model, investigations can be picked up in full stride. The flow model allows managers to quickly evaluate probable flow direction and speed which aids in monitoring well placement (1).

The models are also useful in selecting remedial actions or interim actions which are intended to halt or block the transport of contaminants (1).

Dr. Keely, however, does not feel groundwater models are as useful as many believe. If they are derived from too little data, using too many assumptions, managers will tend to get false impressions of the accuracy of the model. He contends a good surficial geological study will provide enough information to make decisions on monitoring well placement. As with the geophysical investigative techniques, Dr. Keely feels, once adequate information has been gained to validate the model you have probably conducted a full groundwater contamination survey in the process (26).

As previously mentioned, Wright-Patterson AFB is having a complete geological and groundwater survey conducted by the USGS. One of the results of the study will be a computerized groundwater flow model for inclusion in their IRP. The groundwater model will serve several purposes. First it will aid in solving the groundwater contamination problems by helping to define how sub-surface groundwater and other water sources such as streams, rivers, lakes and ponds will interact if pump and treat methods are used during remedial action activities. It will also provide information on groundwater draw down from pumping activities which will help determine the ultimate pumping rate during these cleanup activities (39).

The second purpose will be to assist in determining the effect pumping may have on well fields in the surrounding areas of Wright-Patterson. There are several private and municipal well fields in close proximity to the base and pumping activities may lower these well fields to undesirable levels. The computer model will help predict those effects and, therefore, will help in selecting sites and capacities for extraction wells that will best suit remediation needs and protect surrounding well fields. "Computer models can be used as a tool to perform a lot of the 'what if' situations with respect to groundwater movement" (39).

Environmental Staffing

The issue of insufficient manpower and technical staffing quickly came to the forefront as a major contributor to many problems experienced in administering an IRP. Staffing, or the lack thereof, was attributed to problems ranging from lack of attention, communication and management emphasis to program cost overruns and ineffective review of technical reports.

Mr. Arthur Chen, Environmental Coordinator for the 93rd Bomb Wing, Castle AFB, CA (SAC) identified several problems associated with lack of staffing. He stated:

> Castle [AFB] is five years behind in the remediation program as far as I can see. The problem out here is they have no continuity on the staff at the base level. Now they are trying to get the people to stay here longer. Right now Castle is trying to get four or five people to come in but the problem is the grade [GS pay grade level] does not justify the experience. . . .

> Funding is not a problem [for investigation], we always get sufficient funding from DERA money. Just getting the people who know how to use it and will stay with it is the problem. . . . I came from the private sector with twelve years experience. Once I came in I found out that base level [engineering] lacks technical engineers who understand how to run the environmental engineering program. They waste a lot of money. If they have high quality people then they're going to save a lot of Air Force money, particularly on the IRP [8].

Mr. Chen referred to a specific example that occurred at Castle AFB just prior to his arrival. The base received a remediation order from a regulatory agency to repair or replace, within a year, an oil/water separator that was not functioning adequately. It was causing environmental problems and contamination. An inexperienced contractor was hired to submit an estimate, perform the design and effect repairs. The contractor's estimate was in excess of $500 thousand dollars for repairs (8).

After waiting almost a year, Civil Engineering and Mr. Chen, who was recently hired, asked for a progress report on the design and were told none had been made. A new contractor with more experience was brought in. Ultimately, the time it took to design and effect repairs was eight weeks and the contract price was only $7,000 (8).

Mr. Chen pointed out that had Castle AFB employed qualified personnel at the time the original contract was issued they would have been able to monitor the progress of the contract more effectively and spot difficulties much sooner. He said this also applies in conducting the RI/FS within the IRP (8).

Mr. Metz commented that the problems a lot of installations are having boil down to the staffing issue. He said:

> The IRP is a major program, and to have it dumped on the already overloaded environmental and contract planning section without additional staffing initially, has made, in some senses, for an inferior product. If you had a [technical] person on board before you got into the whole investigation, who could spend all of their time on the IRP, a lot of the problems we have been having with the state [regulators] would have been eliminated [35].

Mr. Michael Grenko, Chief, Environmental Management Office, 62nd Civil Engineering Squadron, McChord AFB, WA stated:

> The regulators now have woken up to the fact that when they walk in the door and they see one person trying to field it all [the IRP and hazardous waste management work load] they say, "Aha!" And then they look closer. But when they see a developed staff, they back off. And that's exactly the way they're coming across to me now. They come in here [into the Environmental Section at McChord] and they ask how many people I have and how we're splitting it up [the environmental work load] and they say, "Oh, you're doing OK here," and they go away. It's an entirely different attitude. . . They've learned to look for staffing. Because if you don't have staffing, you obviously don't have much of a program [20].

In many cases, additional staffing has been authorized through the use of DERA funds and a special staffing program. Unfortunately, those slots are often unattractive to top notch technical personnel because of the grade level and pay with which the slots are funded. Many of these slots are only funded for short-term employment which, again, detracts from their appeal.

Mr. Bruce Mero, the IRP Program Manager with the 416th Combat Support Group, Griffiss AFB, NY (SAC) reported that their office currently has two short-term DERA funded positions, both of which are only GS-5s (34).

Mr. Mero is working with the Base Commander to get those positions upgraded to at least GS-9s but they would then be forced to take funds from the general base operations and maintenance (O&M) account to support them. He is concerned, however, that if the positions are not made permanent and the grade levels are not raised substantially, qualified personnel will not take the jobs or hold them for any length of time (34).

According to each headquarters, the current technical manpower staffing for both headquarters and base levels for the four major commands queried are presented in Tables 3 and 4. Technical manpower was classified as staff members who possessed a bachelors degree or better in geology, hydrology, environmental engineering, or a related field.

Mr. Caughman at MAC Headquarters has a GS-12 position that had been open for nearly a year. The position was filled in June 1988. Mr. Caughman claims there are not enough qualified people in the system to fill the positions that are available (7).

Mr. Caughman's assertions are substantiated by Dr. Keely who commented that schools cannot keep up with the demand for qualified technical personnel in all areas of the environmental arena. Geologists, hydrologists, chemists and so forth are all in short supply (26).

Table 3

Technical Manpower at Headquarters Level

Command	No. on Staff	Yrs on Staff	Grade Level
AFLC	1 (2 pos exist)	2.0	GS11/12
MAC	1	.25	GS12
SAC	1	.2	GS12
TAC	2	1.5	GS12/Contract

Table 4

Technical Manpower at Base Level

Command	No. Bases in CMD W/IRP	No. Bases * W/ Tech Staff	Yrs on Staff	Grade Level
AFLC	7	4	1.5 to 2	GS12/13
MAC	13	1	.5	GS12
SAC	25	1	N/A	GS12
TAC	17	17	1 to 2	GS11/Contract

* some bases have technician staff members with lesser degrees who do not appear in this table.

It appears this is a two-fold problem for the Air Force. First, positions are not authorized within some Headquarters and many base-level organizations. Of those positions that are available, many are not attractive to those people who possess the skills and experience because of their low grade levels. The second problem is the lack of qualified personnel graduating from university programs.

Managerial Support

Throughout the DoD the problems associated with administering an environmental program have become evident. Command level emphasis has increased from individual service major commands all the way up to the Pentagon, Congress, and the White House. Top-level managerial support is necessary to insure the IRP receives the attention necessary to operate in the most effective manner, from an administrative as well as a technical standpoint.

Within the DoD portion of the executive budget, the DERA budget was the only major program that was not cut (7). This indicates the program is receiving the financial support it needs.

Though financial support is a major portion of running an environmental program, support must also come in forms more visible and tangible to the public. Million dollar programs have suffered setbacks when partially informed communities and public officials, in close proximity to installations under investigation, have caught top level management off guard with inquiries or when environmental regulators levy notice of violation upon the installation.

Indications are that upper and command level managers and decision makers are becoming more and more aware of the situations and problems associated with environmental issues.

Many bases have taken the initiative to establish environmental task forces to deal with these issues and problems. Because these environmental management offices are generally assigned either directly under the Wing or Base Commanders, they receive much-needed attention.

At Vandenberg AFB, CA (SAC) the 1st Strategic Aerospace Division Commander recognized the impact of the environmental problem and the need for greater emphasis being placed on environmental issues. He established an environmental task force manned with approximately 20 full-time members which is headed up by an Air Force Colonel (38).

The arrangement at Vandenberg AFB is not without problems, however. With the creation of an EM Office separate from Civil Engineering, some tension has resulted. This tension is attributed to the EM office being viewed as another form of regulator requiring Civil Engineering to meet environmental deadlines (32).

At Castle AFB, CA (SAC) the Wing Commander was made aware of the increasing problems associated with managing the IRP from within the depths of the Civil Engineering Squadron. He established an environmental task force directly subordinate to the Vice Wing Commander and has staffed it with seven full-time personnel (38).

According to Captain Sonny Oh, HQ SAC IRP Program Manager, environmental situations at Vandenberg and Castle

Air Force Bases are improving as a result of the environmental office restructuring (38).

Captain Oh stated the IRP often requires Command attention. Unfortunately, many times it takes a series of negative events to draw that attention. ". . . a lot of times the only way we get Command attention is when it [an environmental problem] makes a major newspaper front page" (38). Captain Oh also stated, "A Notice of Violation [of environmental regulation or law] or a series of NOVs or clean-up orders [from environmental regulators] and bad publicity will usually draw Command attention, but the press is the one that normally catches their attention" (38).

Captain William Stutz, IRP Program Manager at HQ TAC, emphasized, "The IRP should not be reduced to the point that money is the bottom line. Environmental concerns are more important than the money involved" (43). He indicated that environmental managers, at all levels, should be aware of program developments and should be knowledgeable of the steps to take in order to best handle those developments (43).

Management Techniques. There are many management techniques and methods that assist Command and lower-level environmental decision-makers in maintaining contact with issues and developments in areas within their sphere of authority.

Captain Stutz indicated good working relationships between all levels of Air Force environmental management and environmental regulators is vital. He and the Tactical Air Command are striving to bridge the gap between the Air Force and local and federal regulators. "Let them know you are working for the same ends [environmental restoration] . . . We must make an effort to eliminate adversarial relationships [between the Air Force and regulators] " (43).

Captain Stutz pointed out that HQ TAC now maintains greater control and representation on base level boards than it did in the past. He feels this emphasizes TAC's upper level management position of support to bases. He also feels this participation at base level communicates to regulators the Air Force is truly concerned over environmental problems. A benefit of this approach is that base representatives do not have to bear the brunt of community, media and regulator pressures. Command can review and intervene when necessary (43).

Captain Stutz also feels this management method keeps HQ TAC more involved in IRP activities at all of its bases and therefore keeps Headquarters better informed of important issues as they arise or change (43).

Other recommendations Captain Stutz felt would enhance management perspective of the overall IRP situation included:

a. Planning and Conducting a Headquarters IRP Conference to discuss and share knowledge regarding the EPA National Contingency Plan format for conducting environmental studies and remediations (43).

b. Conducting an environmental coordinator conference in conjunction with the annual EPA Superfund conference (43).

c. Ensure that IRP projects are ready to take advantage of 'end-of-year funding.' This is generally a practice of the Engineering Design Section at many bases, but Captain Stutz believes the Environmental Section should take advantage of end-of-year DERA funds as well (43).

IRP Continuity and Information Transfer

Although not considered in the original thesis statement of this report, a major problem conveyed by many of those interviewed concerned IRP continuity and information transfer. Many respondents felt this was perhaps the largest cause of ineffectiveness within the IRP. Without adequate means for maintaining program continuity and transferring information regarding the IRP, management is destine to repeat the same mistakes again and again (3).

In many IRP cases, duties were so divided that once a particular agency completed its portion of the IRP they simply handed off the report to the follow-up agency and that was that. Also, under the Phased approach, different contractors were used to perform separate phases of the study. This often creates duplication of effort, sometimes resulting in conflicting analysis.

Mr. Andrew Allen, HQ MAC, Chief, Engineering and Environmental Branch, stated he attended an Air Force wide "IRP Technology Transfer Conference" held at the AF Engineering and Services Center, Tyndall AFB, FL in February 1988. He was distressed about a perceived deficiency in the way IRP information is handled and conveyed (3). In a letter to Mr. Gary D. Vest, Office of the Deputy Assistant Secretary of the Air Force, (Environmental Safety and Occupational Health) Mr. Allen stated:

> I'm concerned about the Air Force, Army and Navy lack of meaningful routine environmental technology transfer capability. We in civil engineering need the tools and equipment that will allow us to make intelligent decisions based on the quality of the field data and technical analysis produced. We need to be able to readily interpret the BEE's [Bioenvironmental Engineer's] jargon and be able to act decisively with a reasonable assurance of doing the right things for the right reasons [4].

As stated in the Mathematical and Computer Modeling section of the literature review of this text, very little is currently being done in the area of information systems within the DoD or the private sector (21).

Engineers at the Air Force Engineering and Services Center, Tyndall AFB, FL, are working on the development of an IRP decision support system and data base. According to Lieutenant Michael Elliott of the Center, a decision support system is being developed to assist environmental managers in determining recovery well placement, size and pumping rates for contaminant recovery during remedial actions. Lt Elliott indicated no efforts are being made in the area of remedial investigation strategies (17).

Captain Kamenski of AF OEHL is developing a data base of all available IRP information available to AF OEHL. This data base will eventually hold all of the technical information for the AF IRP program (24). These two developments may help bridge the gap cited by Mr. Allen.

With respect to the continuity issue, Captain Oh, Captain Stutz and Captain Kamenski all agreed the retention of a single contractor to perform the investigative and feasibility phases (RI/FS) of an IRP would benefit the program. In fact, according to these IRP managers, that type of contracting is currently being pursued (38)(44)(24).

Captain Kamenski commented further that civil engineering is getting more and more involved in all phases of most IRPs and the bioenvironmental engineers are gradually phasing out to a support role (24).

Although the civil engineering/single contractor approach is becoming more prominent, there are still installations with programs being conducted using the original four phased method. An IRP Program Manager stated his base continued to operate under the phased approach and terminology. He commented their IRP Phase II stage 2 (quantification) was just being finalized under the supervision of the Surgeon General's Bioenvironmental staff and was ready for transfer to Civil Engineering's control.

The same Program Manager stated that Base Civil Engineering had not been involved to any great extent thus far but was expecting to get involved more heavily as Phase II was completed and Phase IV began.

According to Mr. Wayne Caughman, HQ MAC Chief Environmental Branch, Scott AFB, IL is just beginning its IRP effort. They are converting from the four-phase approach and adopting the NCP approach and terminology. He said that installations that are in the early stages of the IRP will have little trouble changing over to the NCP format. Those installations that are deep into Phase II or even attempting Phase IV are the ones that will experience the greatest difficulty in making the transition. He did not feel, however, that programs would suffer a great deal converting and that most of the information obtained under the phased approach would be of significant use (7).

McChord AFB, A Case Study

One case in point within the Air Force is McChord AFB, WA. McChord's IRP, along with it's hazardous waste program, were being administered within current Air Force guidelines as a portion of the work load of the 62nd Civil Engineering Squadron's Office of Environmental and Contract Planning.

IRP investigations began at McChord in March 1982 with the Phase I Records Search and interview process. The final Phase I report was released in August 1982. A total of 62 contaminated or potentially contaminated sites were identified on McChord. Of the 62 sites, 19 were found not to be potential threats to the environment or to the public and were not scored using the Hazard Assessment Rating Methodology (HARM). The remaining 43 sites were classified using the HARM. As a result of the HARM assessment, some sites were combined and ten general areas were identified as having the highest potential for pollutant migration (41:10).

In October 1982 Phase II, Stage 1 (Confirmation) was undertaken. This phase included a reconnaissance survey of the highest priority sites. The Phase II, Stage 1 report was published in June 1983 and identified the groundwater flow as being in generally a northwest direction and consisted of basically two flow patterns. Unfortunately, the study was not complete enough to sufficiently confirm the extent or sources of contamination of various types that were identified at several areas (41:13).

Phase II, Stage 2 field investigations of the IRP were undertaken between the period of June 1983 and March 1985. Investigations were conducted on a site-by-site or area-by-area basis. Overall installation groundwater flow characteristics were estimated from existing regional groundwater table maps. Again, groundwater was thought to flow to the northwest (41:24). No further investigation of regional groundwater flow characteristics was accomplished.

In McChord's Phase II, Stage 2 report published in April 1986, it was stated that, "The investigations were performed to confirm the type and quantities of groundwater contaminants that may be a consequence of past waste disposal practices . . ." (41:1). This statement indicates contamination would be quantified by the current study.

Despite the intent stated above, the report does not indicate the investigations adequately defined the extent or quantity of contamination. The report refers to Area A, the site of a POL storage tank farm. Area A was identified during Phases I and II as having a great potential for spreading VOC contamination to off base potable groundwater because of JP4 jet fuel spills. The report states, "A shortcoming in the data base continues to be the unknown spatial extent of contamination in the north and northwest direction from the tank farm" (41:145). In other words, the contamination in Area A had not been quantified.

Generally, the Phase II, Stage 2 report failed to quantify contamination at any of the sites considered to be environmentally hazardous. Further study of all sites was recommended.

During the course of investigations many local citizens became aware of McChord's groundwater problems and began following the proceedings. Residents in the American Lake Garden community, immediately adjacent to McChord AFB, began complaining of degraded water quality from their private wells. Some of the residents filed suit against the Air Force and McChord AFB for contaminating their drinking water and, in some cases, for health problems they claimed were related to the contamination. Some of these cases have been settled in favor of the residents, while others are still in litigation (20).

Based on the increase of complaints received from the community, local and federal environmental regulators began taking a closer look at McChord AFB environmental practices.

Representatives from the Washington State EPA and the Tacoma, Pierce County Health Department began making regular visits to McChord. McChord's Hazardous waste management program, also conducted from within the Environmental and Contract Programming Section of Civil Engineering, became the focus of their attention (20).

In a 1985 report from the Washington State EPA, McChord was cited for violations of hazardous waste management regulations regarding the storage and disposition of hazardous substances. The Base was given a one year deadline to remedy the problems. On a subsequent visit, additional problems were identified and a Notice of Violation (NOV) was issued. The NOV cited the new problems and levied a fine of $25 thousand on the Base Commander (20).

Immediately, an Environmental Task Force was established outside of Civil Engineering. This Task Force was answerable directly to the Base Commander and was headed up by an Air Force Colonel (O6). Responsibility for the continuing effort of hazardous waste management and the IRP was placed upon the Task Force (20).

Hazardous waste and IRP management, which had previously been the responsibility of one GS-11 as two of his many duties, was now being administered by a task force which included an AF colonel, a lieutenant, a master sergeant, two sergeants, and the same GS11 (20).

Once the task force had brought the program under control, the office was brought back under the supervision of the Base Civil Engineer as a new and separate section no longer a part of the Environmental and Contract Programming Section. The Chief of the new Environmental Management Section was established as a GS-12 civilian position in June 1986. Other staff members include a GS-12 geologist (added in February 1988), and two GS-9 technicians (added in early 1986). All positions previously filled by military personnel have now been converted to civilian slots (19).

During the Environmental Section's transition period, Area A, mentioned earlier, was the focus of further evaluation and subsequent studies. In the fall of 1985 a study was performed at Area A with the objective of furnishing conceptual designs for remedial measures and providing estimates of associated costs (dames & moore).

The study used existing data and literature as a starting point. Additional site geophysical readings and evaluations were performed. Seven new monitoring wells were added in the area. Combined with the existing five wells, placed in the area during earlier phases of investigation, the study was intended to produce localized groundwater table maps and identify groundwater flow characteristics. All wells, both existing and new, were located within 800 feet of the center of the POL tank farm (11:Figure 1-2).

Based on data derived from this latest study, conflicting groundwater elevations and flow characteristics were identified and contaminated regions could not be adequately defined or quantified. As a result, suggestions for remediation were qualified with recommendations for further investigation and quantification. The report of these findings, submitted in February 1987, states:

> In order to prepare a conceptual design at this preliminary stage some assumptions must be made about the unknown factors. The key unknowns are:
>
> -Presence or absence of floating hydrocarbons north of well AZ06 [a well placed during Phase II activities which revealed high VOC levels].
>
> -The hydrological flow regime variations in time and direction, which affect the movement over time of the hydrocarbons to be recovered.
>
> Until these unknowns ar defined, any conceptual design must be considered preliminary [11:6-1].

The original contract cost of this study was $68,000. The final cost of the project totaled $272,132. This included US Army Corps of Engineers contract administration costs of 30 percent. The Corps was retained as technical advisor due to the lack of technical staff at McChord itself (20).

In late 1986, an attempt was made to remediate the VOC contamination in Area A using an in-situ treatment method of biodegradation. This method of remediation generally takes several months, or even years, before results can be determined. Further monitoring is required to evaluate the effectiveness of the process. The cost of the biodegradation process at McChord was $159,800 (20).

In March of 1988 four additional monitoring wells were placed in the vicinity of Area A in an attempt to locate the boundary of contamination. A well was placed approximately 1600 feet from the center of the POL tank farm. This well did not reveal any contamination. Mr. Grenko estimated the cost of placing the four wells and performing additional site analysis was in the vicinity of $200 thousand. Mr. Grenko stated there will be at least one more similar drilling/study event in Area A before final remedial action design can be undertaken (20).

McChord's efforts in Area A can be compared to the 'Plume Delineation' process as defined by Mr. Jack Dowden and Mr. Larry Johnson in their paper <u>Cost-Benefit Analysis of Alternative Remedial Investigation Methodologies: A Case Study</u>. The process involves an iterative drilling and study or analysis cycle, each of which is termed a 'drilling event.' That process was reviewed and described in the literature review of this report (16:1496,1500-1502).

Area A has already gone through three 'drilling events' and is expected to have a fourth before design is undertaken. The costs of the last two events has come to an estimated $472,000 (20).

Assuming the 'Transport Quantification' method, as described by Mr. Dowden and Mr. Johnson, had been employed at Area A, and assuming it worked as proposed by Mr. Dowden and Mr. Johnson, at a savings of 35 to 45 percent (16:1506), a savings of between $165,200 and $212,400 might have been realized for these last two drilling events alone.

More recently, two of the contaminated areas on McChord AFB were again evaluated using HARM scoring. Based on the results of this evaluation, these areas were placed on the EPA's National Priorities List (NPL). This forces McChord to perform RI/FS studies in these areas following NCP procedures (20).

The first area is identified as Area C, an area adjacent to and including aircraft parking ramp 'C.' JP4 jet fuel and other contaminants were found in the groundwater at this location. The RI/FS study contract for this area was issued in July 1988 for $1.471 million and is expected to run for an additional two years (20).

The second area is identified as Area D, and is located at the base golf course. Area D is a site where barrels of various types of hazardous waste were buried in the past. Area D is attributed with being the most likely source of contamination of the American Lake Garden community mentioned earlier. According to Mr. Grenko, the RI/FS for Area D was issued in July 1988 for $1.5 million and will also take about two years to complete (20).

Without including these two RI/FS projects, McChord's IRP investigation dollar totals are somewhere in the neighborhood of $2.2 million (7). To date no real remedial action plans for contaminant removal have been devised or actuated (20). Potable water, a water line feasibility study, and a water line distribution system for the American Lake Garden community were partially funded with DERA funds. The total for this endeavor was over $2.67 million (7).

Considering all aspects of McChord's IRP, the approximate total DERA expenditures come to $7.9 million. This includes $2.971 million for the RI/FS studies for Areas C and D, the two NPL sites (7)(20).

Summary

The four general issues identified as management emphasis, information and technology exchange, increased geological and hydrological characterization and staffing have been presented. Each of the four issues is directly related to the other three and all are related to the overall effectiveness of the IRP.

The McChord AFB case study is an example of how the IRP has been executed at many Air Force Bases across the country. Although few have experienced the political, regulatory and community pressures McChord has endured, the possibility exists for similar situations to occur.

V. Conclusions and Recommendations

Overview

Over the past 40 or so years, concern over soil and groundwater environmental problems has increased. However, it is only in the last decade that real progress has been made in the area of environmental restoration.

Many contaminated sites throughout the country have been identified but few have actually undergone remedial actions for cleanup and even fewer are 100 percent remediated. DoD and, more specifically, Air Force installations are no different. The majority of the effort, both time and money, has been expended in attempts to identify and quantify contaminated zones.

This thesis identifies some of the potential reasons for ineffective and non-productive IRP programs, as well as strategies for conducting environmental restoration investigations.

Conclusions

Analysis of the information gathered during this research effort has led to the following conclusions regarding the four interest areas within the IRP:

Geological/Hydrological Characterization. The current investigative process followed at many DoD and Air Force IRP sites (that is, to develop and investigate each individual contaminated site on a site-by-site basis) is now being questioned by the technical community. This investigative process often fails to accurately quantify and delineate the contamination zone.

Quantifying and delineating contamination at a site, prior to designing remedial actions, is essential. When complex geological and hydrological systems are involved, it is extremely difficult to accurately perform these tasks.

In order to achieve adequate results from the current process, several repetitions of drilling, study, and analysis are required. Investigations are usually spread across several years and are hindered by the transfer or loss of key personnel or changing of contractors. This process is shortened or eliminated only when emergency cleanup is necessary to protect the public or environment.

The first step in the process of quantifying and delineating contamination of soil and groundwater is to characterize and understand the setting in which they exist. Without a better understanding of these features, the remainder of the IRP will likely be performed with less than sufficient data to adequately design and remediate contaminated sites.

As stated in the Air Force IRP Management Guidance and other government literature, Phase II or the RI portion of the IRP is intended to "confirm and quantify" contamination. It would appear something more is needed during this important phase of the IRP to assist in more completely quantifying contamination zones.

In many cases, research has shown additional time, effort, and money were expended just to provide contractors hired to perform remedial action designs with enough information to make estimates about the size and delineation of contaminants. This does not include the design of a plan for actual removal and treatment of the contaminants.

At this point, the issue is reduced not to whether we can afford to perform additional characterization, but to whether we can afford not to. Granted, the techniques for characterizing a location or region are expensive. However, in light of the fact that current practices in use at most Air Force installations are not producing the necessary results to proceed into design and remediation, something more needs to be done.

A combination of processes described here (computer modeling, geophysical testing, and geological/hydrogeological surveys) will go a long way towards filling that need. The key factor, though, is the completeness and accuracy of the geological/hydrogeological survey.

Existing well records and IRP investigative information may provide an adequate data base to perform the required groundwater movement calculations. A completely new survey may be required, or a combination of new and existing data may suffice. This must be determined by a technically competent individual. Without a sufficient data base to determine the characteristics of the entire aquifer, all other phases of the IRP including remedial action design and remediation will lack necessary accuracy and completeness. The eventual outcome will be lost time and increased expenditures to acquire the needed data.

Review of the McChord AFB case study reveals that the typical Air Force strategy is long and drawn out. Investigations have been underway at McChord for over six years. However, according to all of the IRP reports and statements from officals at McChord, the geological and hydrological settings, which dictate the migration of contaminated groundwater, have not been adequately characterized. Contractors are reluctant to commit as to what forms of remediation would be effective. They cite a need for further characterization as their major concern.

Furthermore, the cost of McChord's IRP for site investigations in Area A alone have topped the $470,000 mark, with more investigation required before feasible alternatives for remediation can be reviewed and recommended.

Environmental Staffing. The most significant result of this research is that staffing in the environmental arena is severely lacking. Persons in positions of authority must be made aware that technically competent personnel are a must if an environmental program is to be effective.

Overwhelmingly, those interviewed pointed to a lack of manning in hydrogeological and environmental technical fields. They also pointed out that those in command and top-level management are often reluctant to fund new positions for technical staff members.

Without proper technical review at appropriate levels (e.g. base and headquarters levels) plans and reports can merely be reviewed from an administrative standpoint. However, it is at these levels that most of the technical and monetary decisions are made.

In many cases, multi-million dollar programs are assigned to overworked and understaffed Environmental and Contract Planning Sections buried deep within the civil engineering squadron. The IRP is often assigned as an 'additional duty' to a staff member who has numerous other tasks to perform and is neither administratively nor technically qualified to review environmental contractor proposals and resulting investigative data. Yet, these are the individuals who eventually make recommendations for decisions relating to further investigative and remedial activities.

Top-level management has recognized the problem of staffing exists. Unfortunately, positions funded through the Defense Environmental Restoration Account at the installation level are generally temporary positions and are graded so low they are not attractive to qualified technical personnel.

Without providing assurance of long-term employment at a salary commensurate with the knowledge and experience of the individual, and comparable with that of the private sector, the government cannot expect to attract the personnel it so dearly needs to conduct and administer the IRP. Such personnel may temporarily take an assignment within the GS structure, but history has shown that when a better offer comes along, these personnel will usually resign at the opportunity for positional and monetary advancement.

As evidenced by the McChord AFB case study, DoD and Air Force IRPs are often administered and managed without the technical expertise and top-level management attention they need to run effectively and economically. Many of the bad experiences at McChord could have been avoided if the environmental section at the base had been staffed with technically qualified personnel prior to the onslaught of problems.

Properly staffed, the McChord environmental office could have made changes in its management of the hazardous waste program, thus reducing the likelihood that regulators would find significant instances of non-compliance in that program.

As indicated by Mr. Grenko, the current Chief of the Environmental Section at McChord, the fact that the section is staffed by technically qualified personnel, at this time, has significantly improved the perception regulators have of the capabilities of the section.

With the addition of a geologist to the McChord staff six months ago, Mr. Grenko has gained confidence in the ability of his office to monitor the execution of environmental investigative efforts under the IRP, as well as its ability to analyze the results and conclusions drawn by contractors performing those investigations. Likewise, he is better able to communicate those findings to his superiors, thus allowing them to be better managers.

Management Emphasis. Although not included as part of the original hypothesis of this thesis, it was found that in order to achieve the necessary results within the IRP, management at all levels must be made more aware of the extensiveness of environmental problems and their impact on the community and on the mission of the Air Force. If management fails to support the program wholeheartedly, embarrassing and often disastrous results can occur.

Again, top-level management is getting the picture and steps are being taken to improve the program. Adoption of EPA's NCP process will help bring DoD environmental managers and federal regulators closer together as far as program execution is concerned.

Reflecting on the situation at McChord AFB, it is apparent that during the early stages of IRP activities there, appropriate attention was not placed on the program. With the advent of regulatory and community pressures, it became evident that in order to adequately administer the

IRP, increased attention from top-level-management was required.

Since the inception of 'Town Meetings' and base-wide organizational working groups, McChord's IRP program has gained great respect from regulators and citizens alike.

Information and Technology Transfer. Information and technology transfer within the IRP is lacking. Little information has been transmitted for dispersion throughout the environmental community. Individual programs are often disrupted by changes of contractors or within administrative offices.

The initiation of an IRP central data base system at the AF OEHL and the development of an Environmental Decision Support System by the Air Force Engineering and Services Center at Tyndall AFB, FL will help bridge the communication and information transfer gap that exists within the program today.

Placing full responsibility upon a single administrative management staff such as an engineering environmental section or office, rather than dividing the tasks between agencies, has helped bring programs under control at many installations.

Again considering the case of McChord AFB, it is probable the lose of continuity of the IRP through the change of management control from the SG Bioenvironmental Engineer to Base Civil Engineering during early stages of the program and subsequent changes of contractors resulted in the regression from the Phase IVA (FS) in Area A, back into Phase II (RI). A single management/contracting force, and/or more complete information transfer might have averted that occurrence.

Had McChord's Environmental Section been properly staffed from the outset, it is possible, much time, effort, and money might have been saved.

Recommendations

Recommendations for improving the four general areas, geological/hydrological characterization, environmental management staffing, management emphasis, and information and technology transfer, are presented in this section. Recommendations for further research are also included.

Geological/Hydrological Characterization. As noted, many installations are already performing or intend to perform location (base) specific rather than site (contamination source) specific geological/ hydrogeological surveys. It is not necessary for all installations to follow suit, but in cases where Phase I or Site Investigation of the IRP has determined contamination may exist at several sites and the potential exists that other sites may be identified in the future, a complete survey is recommended.

In cases where significant physical exploration has already occurred but final delineation of contamination plumes has not been achieved, complete surveys may still be appropriate and necessary to aid in estimating the boundaries of contamination. Depending on the placement of existing wells and their method of completion, many existing wells may be incorporated into the survey as collection and sampling points.

MAJCOMs and installation IRP managers should evaluate the status of their programs to determine if geological/ hydrogeological surveys are useful.

Environmental Staffing. Since there currently exists more jobs for qualified technical personnel than there are personnel available to fill those positions, the law of supply and demand takes effect. In order to get the necessary personnel to administer the programs, the government must be willing to pay the price, which, incidentally, is much cheaper than running an errant IRP program.

To meet the need for management emphasis and technical staffing at the installation, environmental management offices which are part of the civil engineering organization may be established. They should be created as a separate branch or section, no longer confined to the standard environmental and contract programming section.

Many installations have created Environmental Management Offices which report directly to the Installation or Operational Commanders, by-passing the Civil Engineering organizational structure. This may be an appropriate organization for installations with larger scale environmental problems.

Environmental management offices should be staffed with a GS-12 or higher who will administer the program. The position description should require an engineering or environmental degree and should recommend three to five years of experience.

A second position within the environmental office should be slotted for a geologist, hydrologist or hydrogeologist. This position should have a grade level of GS-11 or higher and should also require several years of experience. Further staffing needs can be made up of administrative and technical personnel as required.

Without appropriate staffing, the IRP will continue to suffer from a continuing lack of expertise and experience. Studies will continue to overrun in both budget and time. Likewise, decisions concerning technology and investigative strategies will continue to be made, in many instances, by personnel who lack the required technical knowledge and experience.

An area of further research may be to quantify how environmental management offices can best be organized and staffed to handle the environmental requirements of the Air Force's varied installations.

<u>Management Emphasis</u>. The IRP process relies on the decisions made by top-level management concerning how the

program is to be run. If management chooses to think lightly of issues regarding technical questions, community relations, and program structure, the IRP will continue to fall behind and eventually will cost more, both financially and in the way it is perceived by regulators and neighboring communities.

Installation and Operational Commanders should conduct and be involved in community or town meetings. These Commanders should also hold quarterly or bi-annual environmental update meetings where other high-ranking individuals from the installation are kept informed of IRP and other environmental happenings. McChord AFB has adopted both of these practice as part of their IRP management program with great success.

All managers should be aware of the link between hazardous waste practices and possible soil and groundwater contamination. Keeping operational managers informed may help eliminate contamination problems in the future.

Management, at every level, must show an increasing interest in the IRP and become better educated in its administration and execution.

In short, managers should be knowledgeable about all aspects of the IRP to the extent that they will be able to make informed decisions and present a good impression upon regulators and the community.

Information and Technology Transfer. As pointed out by Mr. Allen of HQ MAC, the DoD needs to develop and implement an interservice-wide information transfer and technology exchange system. This is no simple task. This research did not delve into that aspect of the IRP adequately to be able to draw any strong conclusions about how to handle the problem.

Further research should be performed in this area looking closely at the efforts of the AFOEHL's IRP data base, the AF Engineering and Services IRP Decision Support System and those of the other services as well.

Summary

Certainly, implementing the above mentioned changes within the IRP will require additional expenditures up front but the final outcome will be a better understanding of the entire groundwater picture beneath the installation, ultimately resulting in a more completely restored environment.

Although initial costs may be higher, it is probable that total costs would be reduced. This is based on the 35 - 45 percent savings estimated by Dowden and Johnson when the 'Transport Quantification' strategy is used.

However, without adequate technical staffing to make appropriate decisions and recommendations along the way it would be difficult to take full advantage of those savings.

Appendix A: Personal Interviews

Capt. James Aldrich
IRP Program Manager, Environmental Management Section
HQ Air Force Logistics Command (AFLC)
Wright-Patterson AFB, OH

Mr. Andrew Allen
Chief of Engineering
HQ Military Airlift Command (MAC)
Scott AFB, IL

Col Byrne
Chief, Environmental and Contract Programming
HQ Space Command
Peterson AFB, CO

Mr. Henry W. Caughman
Environmental Program Director
HQ Military Airlift Command (MAC)
Scott AFB, IL

Mr. Arthur Chen
IRP Program Manager
93rd Bomb Wing (SAC)
Castle AFB, CA

Mr. Allan Dalpais
IRP Program Manager
2849 Civil Engineering Squadron (AFLC)
Hill AFB, UT

Lt. Michael Elliott
Project Manager
USAF Engineering and Services Center
Tyndall AFB, FL

Mr. Joseph k. Fitzgerald
Geologist, Environmental Management Section (IRP)
HQ Tactical Air Command (TAC)
Langley AFB, VA

Major Mark Goltz
Head, Department of Management Applications,
School of Civil Engineering and Services
Air Force Institute of Technology (AFIT)
Wright-Patterson AFB, OH

Mr. Michael Grenko
Chief, Environmental Section
62nd Civil Engineer Squadron (MAC)
McChord AFB, WA

Mr. Mario Ierardi
IRP Program Manager
Systems Management-Air Logistics Center (AFLC)
McClellan AFB, CA

Colonel Donald Kain
Chief, Environmental Section
United States Air Force (USAF Air Staff)
Pentagon, Washington, D.C.

Capt Art Kamenski
Bio-Environmental Engineer
Chief, Technical Analysis Function
United States Air Force
Occupational and Environmental Health Laboratory (USAF OEHL)
Brooks AFB, TX

Mr. Scott Mallette
Environmental Engineer, Environmental Management Office
2750th Air Base Wing (AFLC)
Wright-Patterson AFB, OH

Mr. Robert Martian
Chief, Environmental Management Office
Systems Acquisition-Air Logistics Center (AFLC)
Kelly AFB, TX

Major Menzie
Chief, Engineering and Environmental Branch
4392 Civil Engineering Squadron (SAC)
Vandenberg AFB, CA

Mr. Bruce Mero
IRP Program Manager
416th Civil Engineering Squadron (SAC)
Griffiss AFB, NY

Mr. William Metz
IRP Program Manager
90th Civil Engineering Squadron (SAC)
F.E. Warren AFB, WY

Mr. Daniel Mooney
IRP Program Manager
439th Civil Engineering Squadron (MAC)
Charleston AFB, S.C.

Mr. Michael Nicklow
IRP Program Manager
379th Civil Engineering Squadron (SAC)

Mr. Stuart Reese
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2750th Air Base Wing (AFLC)
Wright-Patterson AFB, OH

Capt. Sonny K. Oh
IRP Program Manager, Environmental Management Section
HQ Strategic Air Command (SAC)
Offutt AFB, NE

Capt. William J. Stutz
IRP Program Manager, Environmental Management Section
HQ Tactical Air Command (TAC)
Langley AFB, VA

Lt. David Wannigman
Bio-Environmental Engineer
USAF Clinic (MAC)
McGuire AFB, NJ

Appendix B: List of Acronyms

AFLC	Air Force Logistics Command
AF OEHL	Air Force Occupational and Environmental Health Laboratory (also USAF OEHL)
CE	Civil Engineer
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
D&N	Discovery and Notification
DERA	Defense Environmental Restoration Account
DERP	Defense Environmental Restoration Program
EM	Electromagnetics also Environmental Manager or Environmental Management
ER	Electrical Resistivity
FS	Feasibility Study
GAO	General Accounting Office
GM	Geomagnetics
GPR	Ground Probing Radar also Ground Penetrating Radar
HARM	Hazard Assessment Rating Methodology (NCP)
HQ	Headquarters
HRS	Hazard Ranking System (IRP)
IRP	Installation Restoration Program
MAC	Military Airlift Command
NCP	National Contingency Plan
NPL	National Priority List
O&M	Operations and Maintenance
PA	Preliminary Assessment

PCM	Post Closure Monitoring
QA/QC	Quality Assurance/Quality Control
RAP	Remedial Action Plan
RCRA	Resource Conservation and Recovery Act
ROD	Record of Decision
SAC	Strategic Air Command
SARA	Superfund Amendments and Reauthorization Act
SG	Surgeon General
SI	Site Investigation also Site Inspection
TAC	Tactical Air Command
USGS	United States Geological Survey
VOC	Volatile Organic Compound

Bibliography

1. Aldrich, James, Captain, IRP Program Manager. Personal Interview. Environmental Management Section HQ Air Force Logistics Command (AFLC), Wright-Patterson AFB OH, 8 March 1988.

2. -----. Telephone Interview. HQ Air Force Logistics Command (AFLC), Wright-Patterson AFB OH, 18 August 1988.

3. Allen, Andrew, Chief of Engineering. Personal Interview. HQ Military Airlift Command (MAC), Scott AFB IL, 16 March 1988.

4. -----. Personal Correspondence. HQ Military Airlift Command (MAC), Scott AFB IL, 2 March 1988.

5. Andreu, Joaquin, Assoc. Professor, Escuela de Caminos, University Politecnica de Valencia, Valencia Spain, and Sahuquillo, Andres, Professor, University Politecnica de Valencia. "Efficient Aquifer Simulation in Complex Systems," Journal of Water Resources Planning and Management, Vol. 113, No. 1: 110-129 (January 1987).

6. Byrne, Colonel, Chief, Environmental and Contract Programming. Telephone Interview. HQ Space Command (SPC), Peterson AFB CO, 22 June 1988.

7. Caughman, Henry W., Environmental Program Director. Personal Interview. HQ Military Airlift Command (MAC), Scott AFB IL, 24 March 1988.

8. Chen, Arther, IRP Program Manager. Telephone Interview. 93rd Bomb Wing (SAC), Castle AFB CA, 20 June 1988.

9. Conservation Foundation, The, "A Guide to Groundwater Pollution: Problems, Causes, and Government Responses," Groundwater Protection. Washington DC.: The Conservation Foundation, 47-204, 1987.

10. Dalpais, Allan, IRP Program Manager. Telephone Interview. 2849 Civil Engineering Squadron (AFLC), Hill AFB UT, 22 June 1988.

11. Dames & Moore, Consulting Engineers. "Report on Restoration of Contaminated Area 'A' Fuel-Contaminated Ground Water, McChord AFB Washington." Report to Department of the Army, Seattle District, Corps of Engineers, Seattle WA, 4 February 1987.

12. Deegan, John, Jr. "Looking Back at Love Canal," Environmental Science Technology, Vol 21, No. 5: 421-426 (May 1987).

13. Department of the Air Force. Air Force Installation Restoration Program Management Guidance, July 1985.

14. Department of the Air Force. Proceedings of the Air Force Installation Restoration Program Workshop. (no page numbers). Several CONUS locations 1987.

15. Department of the Air Force. US Air Force Correspondence, FY88 DERA Eligibility/Programming Guidance (ltr w/two atch). Distribution, Air Force wide. 24 September 1987.

16. Dowden, Jack, Waste Management of North America, and Johnson, Larry, Foth & Van Dyke and Associates. "Cost-Benefit Analysis of Alternative Remedial Investigation Methodologies: A Case Study," Proceedings of the Second National Outdoor Action Conference. Vol. III, 1495-1507. Las Vegas NV, March 1988.

17. Elliott, Michael, Lieutenant, IRP Project Manager. Telephone Interview. USAF Engineering and Services Center, Tyndall AFB FL, 23 August 1988.

18. Fitzgerald, Joseph K., Geologist, Environmental Office. Personal Interview. HQ Tactical Air Command (TAC), Langley AFB VA, 13 May 1988.

19. Grenko, Michael, Chief, Environmental Section. Telephone Interview. 62 Civil Engineering Squadron (MAC), McChord AFB Washington. 18 April 1988.

20. -----. Telephone Interview. 62nd Civil Engineer Squadron (MAC), McChord AFB WA, 12 August 1988.

21. Hushon, Judith M., Roy M. Weston, Inc. "Expert Systems For Environmental Problems," Environmental Science and Technology, Vol. 21, No. 9: 838-841 (September 1987).

22. Ierardi, Mario, IRP Program Manager, Environmental Management Office. Personal Interview. Systems Management-Air Logistics Center (AFLC), McClellan AFB CA, 18 March 1988.

23. Jaffe, Martin and DiNovo, Frank, Local Groundwater Protection, Washington DC: American Planning Association, 1987.

24. Kamenski, Art, Captain, Chief, Technical Analysis Function. Telephone Interview. United States Air Force Occupational and Environmental Health Laboratory (USAF OEHL), Brooks AFB TX, 22 June 1988.

25. Keely, Joseph, Ph.D. Water Research Laboratory, Dept. of Chemical, Biological and Environmental Sciences, Oregon Graduate Center, and Boating, Kwasi, Project Manager, Roy F. Weston, Inc. "A Call For New Directions In Drilling and Sampling Monitoring Wells," Detection, Control, and Renovation of Contaminated Ground Water, New York: American Society of Civil Engineers, 1987.

26. Keely, Joseph, Ph.D., Environmental Consultant to EPA, Water Research Laboratory, Dept. of Chemical, Biological and Environmental Sciences. Telephone Interview. Oregon Graduate Center, Beaverton OR, 17 June 1988.

27. Lehr, Jay H., Ph.D. Executive Director, National Water Well Association, and Wayne A. Pettyjohn, Ph.D. Professor, Ohio State University. "Ground Water Flow No Longer A Mystery," Journal of Environmental Health, Vol. 38, No. 4: 242-250 (January/February 1976).

28. -----. "Our Children Need Not Fear For Their Water," Paper presented at Proceedings of the Air Force Installation Restoration Program Workshop. (no page numbers). Several CONUS locations 1986.

29. Mallette, Scott, IRP Program Manager. Personal Interview. 2750 Air Base Wing Environmental Management Office, Wright-Patterson AFB OH, 2 Feb 1988.

30. Martian, Robert, IRP Program Manager. Telephone Interview. Systems Acquisition-Air Logistics Center (AFLC), Kelly AFB TX, 20 June 1988.

31. McLaughlin, Dennis, Associate Professor, Dept of Civil Engineering, M.I.T. and Johnson, William K. Civil Engineer, Hydrologic Engineering Center, Corps of Engineers. "Comparison of Three Groundwater Modeling Studies," Journal of Water Resources Planning and Management, Vol. 113, No. 3: 405-421 (May 1987).

32. Menzie, Kenneth, Major, Chief, Engineering and Environmental Branch. Telephone Interview. 4392 Civil Engineering Squadron, Vandenberg AFB CA, 22 July 1988.

33. Mercer, James W., President, GeoTrans, Inc. et al. "Modeling Ground-Water Flow at Love Canal, New York," Journal of Environmental Engineering, Vol. 109, No. 4: 924-942 (August 1983).

34. Mero, Bruce, IRP Program Manager. Telephone Interview. 416th Civil Engineering Squadron (SAC), Griffiss AFB NY, 20 June 1988.

35. Metz, William, IRP Program Manager. Telephone Interview. 90th Civil Engineering Squadron (SAC), F.E. Warren AFB WY, 20 June 1988.

36. Nicklow, Michael, IRP Program Manager. Telephone Interview. 379th Civil Engineering Squadron (SAC), Wurtsmith AFB MI, 22 June 1988.

37. Office of the Deputy Secretary (Environment), U. S. Department of Defense. Effects of Superfund Amendments and Reauthorization Act on the Secretary of Defense and Department of Defense Installations (DRAFT), April 1987.

38. Oh, Sonny K., Captain, IRP Program Manager, Environmental Management Section. Telephone Interview. HQ Strategic Air Command (SAC), Offutt AFB NE, 20 June 1988.

39. Reese, Stuart, Geologist, Environmental Project Manager. Personal Interview. 2750th Air Base Wing, Environmental Management Office, Wright-Patterson AFB OH (AFLC), 17 June 1988.

40. Schowengerdt, Richard, Geotechnical Project Manager, International Technology Inc., "An Overview of Ground Water Monitoring Techniques," Detection, Control, and Renovation of Contaminated Ground Water, New York: American Society of Civil Engineers, 1987.

41. Science Applications International Corporation (SAIC), "Installation Restoration Program, Phase II - Confirmation/Quantification, Stage 2, McChord Air Force Base, Washington." Report to USAF OEHL, Technical Services Division, Brooks AFB TX, 30 April 1986.

42. Sowers, George F., Regents Professor of Civil Engineering, Georgia Institute of Technology; Senior Vice President and Consultant, Law Engineering Testing Company. Introductory Soil Mechanics and Foundations: Geotechnical Engineering, (fourth Edition). New York: Macmillan Publishing Company, 1979.

43. Stutz, William J., Captain, IRP Program Manager, Environmental Management Section. Personal Interview. HQ Tactical Air Command (TAC), Langley AFB VA, 13 May 1988.

44. Thielen, Daniel R. et al. "Delineation of Landfill Migration Boundaries Using Chemical Surrogates," Environmental Science Technology, Vol. 21, No. 2: 145-148 (February 1987).

45. Tung, Yeou-Koung, Asst Professor, Wyoming Water Research Center and Dept of Statistics, University of Wyoming. "Groundwater Management by Chance-Constrained Model," Journal of Water Resources Planning and Management, Vol. 112, No. 1: 1-19 (January 1986).

46. United States General Accounting Office, "Status Of Air Force Efforts To Deal With Groundwater Contamination Problems At McClellan Air Force Base," GAO Report NSIAD-84-37, November 1983.

47. United States General Accounting Office, "Tinker Air Force Base Is Making Progress in Cleaning Up Abandoned Sites," GAO Report NSIAD-87-164BR, July 1987.

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ABSTRACT

Groundwater contamination has become a major issue of consideration throughout the country. Department of Defense officials have taken steps to insure water at DOD installations is monitored for contamination under the Installation Restoration Program (IRP)

DOD IRP Remedial Investigations (RI) are often too long and drawn out. The goal of RI is to confirm and quantify soil and groundwater contamination. Often, RI costs exceed estimates and time schedules. Environmental regulators and local residents become distressed over the apparent lack of progress being made.

Current RI strategies employed at most Air Force installations involve contamination plume delineation. This strategy for investigation often does not reveal adequate information regarding movement of contaminants.

A thorough understanding of the hydrogeological setting is essential to obtain maximum improvement of groundwater quality.

An alternative strategy is Transport Quantification (TQ), a process that identifies and quantifies groundwater flow characteristics prior to, or during, contamination investigation. TQ emphasizes surficial and geological investigations and incorporates groundwater flow models.

Preliminary investigations focusing on soil and groundwater characterization can greatly reduce the effort and expense of groundwater investigation and restoration.

It was also found that a severe lack of manning within the environmental function exists. Without technical personnel administering the IRP, the program will continue to be run ineffectively.

The study revealed a need for better data transfer and communication between base level offices and higher headquarters, between headquarters, and between services. The AF Engineering and Services Center and USAF OEHL are working on solutions to these problems. (Thesis. FR)

It is necessary to increase emphasis on the IRP at all management levels. Positions must be funded for technical staff with salaries commensurate with the civilian sector. New investigative strategies must be considered with open-mindedness; not centered entirely on cost, but also on the effectiveness of the process.